

# International Conference for **Sustainable Design of the Built Environment** **SDBE 2017**

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*Proceedings*



*Editors*

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Jack Clough*



**SDBE**  
Sustainable Development  
of the Built Environment



  
**University of  
Strathclyde**  
Glasgow

## Foreword

The International Conference for Sustainable Design of the Built Environment SDBE 2017 forms one of the key deliverables of the British Council Newton Institutional Links Fund project: Building Capacity for Sustainable Development of the Built Environment (BC-SDBE) launched in April 2016. The aim of the BC-SDBE institutional link project is to bridge the gap between the rapidly developing advancements in research and training in sustainable development of the built environment globally, the demanding professional development required in Egypt's construction labour market, and the national plans for the country's economic development. The main objective of BC-SDBE project is to build capacity in education, research, innovation, and exploitation of state-of-the art sustainable development strategies to help promote and sustain socio-economic growth in Egypt.

SDBE 2017 conference offered a unique opportunity for academics, researchers, architects, urban designers, engineers, and professionals to meet and share the latest knowledge, research and innovations on low carbon building design, building performance, simulation tools and energy efficient building-related technologies. The conference focuses on sustainable design, building energy performance, sustainable planning of neighbourhoods and cities, emphasising a balanced approach to environmental, socio-economic and technical aspects of sustainability. The topics extend to include innovative approaches for education and training on sustainability of the built environment. The conference also raises awareness to state-of-the-art strategies and best practice across the world with regards to integrating sustainable development approaches in the built environment.

The book of abstracts includes all 106 papers accepted for the conference under 12 themes clustered into 6 thematic groupings. The full conference proceedings are available to download at <http://newton-sdbe.uk/conferences/sdbe-conference-2017/>

On behalf of the SDBE 2017 Organising Committee, I hope the research papers hereby presented help stimulate further ideas for research in the near future.

We would also like to take this opportunity to invite you to submit abstracts to the second SDBE 2018.

Yours sincerely,

Heba Elsharkawy, BC-SDBE Principal Investigator



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## Editors

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*Chapter 1:*  
*Education for sustainability*  
*Innovative didactics for sustainable*  
*development*



# Striving for Sustainability; A staff and student approach

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**Abstract:** As educators, we are acutely aware of the need for the future generations to be interested in and design for sustainability. With changing climate and increased consumer awareness, the role of architectural design is becoming increasingly essential to reduce carbon and our footprint on the planet. We design into the Architectural Technology curriculum a variety of methods for learning about low energy design including activity led learning at year 1 and BREEAM accreditation at year 2, however how successful and inspirational has this been from the student perspective? This paper will look at and analyse the impact of both activity led learning and traditional lecture methods to investigate the impact on students thinking on their overall awareness and incorporation of sustainability into their design projects, together with learning points from both sides.

**Keywords:** Education, Sustainable design, Architectural Technology, Activity led learning

## Introduction

Sustainability is an essential part of design education. With the resources on the planet becoming progressively scarcer and buildings contributing over 32% of total global final energy use in 2010 alone (Lucon et al, 2014), there is both a moral and educational requirement to teach about the and to integrate sustainability with education.

At Coventry University, the principles of Activity Led Learning (Wilson-Medhurst and Glenning, 2009) are very much encouraged, and as a teaching team we develop the curriculum not only as a response to industry and CIAT requirements, but also in response to successful student learning and feedback.

As part of all of our projects we expect sustainability to be automatically included within the design therefore it has become embedded in the students' minds as an essential part of design process as would be client requirements, security or other important aspects. We do however need to understand whether the taught approach and learning actually correlate from the student perspective

The purpose of this paper is to therefore gain a thorough and unprompted understanding from a student perspective as to the main benefits of the variety of teaching. Perspectives were sought from the highest achieving sustainable project applicants as to their feedback. Interviews were conducted with both students and staff to gain their opinions about the techniques, and learning points for future development.

## Literature Review

Students are constantly required to work in teams (Bogdanovic et al, 2016), and they are encouraged to learn by a variety of teaching methods (Iyer, 2015).

Within the Architectural Technology course there are several books and technical documents that assist their learning. Advanced building technologies (Syed, 2012)

contributes with a variety of deep lying subjects, such as, but not limited to; Quality of life benefits, finite resources, profits and savings of energy efficiency, carbon footprint, radiant cooling, ventilation, chilled beams and air distribution, high performance envelopes and facades, thermal storage, solar options and geothermal.

Energy conservation and the performance of buildings is now a long-established focus point for design and teaching. The code for sustainable homes, 2006 hoped to help reduce carbon emissions for 25 million homes and from 2016 all newly built homes to be zero carbon. 'Net zero emissions are measured by comparing the carbon emissions produced in consuming on – or off-site fossil fuel energy use in the home with the amount of on-site renewable energy produced' (Chudley and Greeno, 2016). Many of the technologies required for are taught with additional technologies such as micro generation, such as, air source and ground source heat pumps.

Approved Document Part L of the UK Building Regulations now incorporates much of the new technical standards and energy efficiency expectations, which in an ever-changing need can be amended when necessary.

Production of materials forms a large percentage of carbon emissions, indeed, 'buildings themselves produce less carbon in operation in CO2 release associated with the materials in embodied energy and carbon becomes more significant, and this induces the production process.' (Byran, 2010). When this is the case it is important to recognise the 'cradle to grave' concept and how intrinsically this should be incorporated into teaching, discussing waste and travel distances for deliveries or materials. The end of life has proved a difficult aspect in terms of demolition operations, at present 'brick and concrete can be crushed on site to produce fills, while steel can be collected for recycling. Timber can be selected for reused or sent to be processed into timber based composites or for fuel' (Bryan, 2010). The prospect of designing for de-construction is now a used system in teaching and incorporated into final research dissertations, the benefits of design for deconstruction according to [designingbuildings.co.uk](http://designingbuildings.co.uk) include:

- Reduction in the whole-life environmental impact of a project.
- Minimising construction waste.
- Minimising costs.
- Helping the local economy.
- Reducing transportation.
- Reducing carbon impact.
- Minimising pollution.
- Reducing the quantity of materials being taken to landfill.

Therefore, design and good technical efficiency should lead the way and our students should be on the front line once they have graduated, with a mentality of 'anything that we build today should be sustainable throughout its lifespan' (Pohl, 2011). Our role as educators is therefore to encourage awareness and enthusiasm in all of the above.

## Method

We have introduced environmental awareness in a variety of diverse ways, including laboratory based learning, lecture based learning and project based learning. The success or otherwise of the integration is measured by the students' abilities to incorporate both consciously and subconsciously the learning into their work.

### ***Project based delivery***

Architectural education is widely known to be project based (Roberts, A 2007), with learning by doing, however in the Architectural Technology course at Coventry University, we are using this studio based approach to teach and demonstrate learning, alongside more traditional construction teaching methods.

The first semester in year 1 involves an introductory design project backed up with a series of small lectures about the importance and ways of thinking about daylighting, sunlighting and shading as well as the position of the building on site and analysis of site conditions. Through understanding why the issue was important (Sinek, 2017), the aim was to introduce the issue of environmental responsibility. Making the environmental element a proportion of the marked assessment for this project forced students to engage with sustainability.

The second project in year 1 was a pedagogical experiment with an optional design competition was used as a basis. The brief contained sustainable material requirements (Bibbings et al, 2017) as well as design based requirements. The paper *'Enhancing Creativity and Independent Learning of Architectural Technology Students through the use of a Real Life Design Competition Module'* (Bibbings et al, 2017) has been written to demonstrate the success of the experiment, however in addition to the brief, students were expected to apply their knowledge without formal lectures or presentations. This ensured that they applied the facts and criteria learnt in the other areas of the course.

### ***Taught content***

In addition to the projects, a separate lecture series was run to act as additional backup, but this time for all 90 building students. With six lectures on each topic of daylighting, thermal conductivity and materials, the learning builds on that of the project learning of the previous semester. Laboratory sessions were designed to test formal lecture learning and to inspire students to want to learn and engage more in the topic (Figure 1). An examination was held at the end to assess knowledge in a formal way.

### ***Professional certification***

In 2017, the sustainable teaching in year 2 has built upon that of year 1, with the introduction of a BREEAM Approved Graduate qualification into the construction module. BREEAM is an important element for construction and architectural industry practices as it allows the ability 'to drive sustainability across the built environment and on a global scale' (BREEAM, 2017). Together with LEED, these are the two most recognised building assessment methods used in the UK. The final outcome of their taught and professional certification content in year 2 requires them to integrate their findings into a low energy commercial design project, which links the learning across all modules.

### ***Linking knowledge***

In year 3, our students undertake dissertations of their own choosing, many of whom pick sustainable measures to be incorporated into their main building design project. This has included maximising solar panel usage, geothermal energy, use of structural insulated panels. Topics such as green roofs, walls, use of photovoltaics and ways of maximising daylighting are also popular choices. The students are expected to incorporate their learning into their project in a very visible way together with consideration of materials, site and surroundings which by now are standard practice.

## **Staff perspective**

### ***Outputs***

In previous years, first year students in general, although given the knowledge about sustainability across various modules tended to not apply it in its entirety within their projects to link the information from taught modules into their design, instead treating issues as separate entities and outcomes. Within second year, we started to see better integration as the buildings are larger and more complex, multi storey in nature and require more thought about the overall needs of the user but due to having more to consider within their designs tended to push sustainability further down the list of considerations.

In third year however, we usually see a much better integration of technologies and sustainable systems which leads to well over 25% of the class choosing sustainability as their primary research aim, and incorporating this within their final design project by choice and not by tutor or mark imposition.

Feedback from students in recent years clearly showed that the laboratory sessions were particularly interesting and a fun way of learning, and whilst they did not actually apply the knowledge as much in their projects, they remembered the delivery of the sessions more and were enthused to research more about the topic on their own.

### ***Time management***

Whilst we felt that the students learnt a lot from the variety of different methods of learning, the individual sessions particularly the labs sessions took up extensive staff time and were held outside of standard teaching timeslots. This resulted in less than usual attendance, however those that did attend were very enthusiastic about the activities. The laboratory sessions are also time consuming, for example the concrete takes a month to cure, so the organisation is required well in advance.

There was also a lead in time for the BREEAM assessment so communication was required consistently and well in advance to ensure that the correct BRE assistance and resources were available, as well as sufficient room space within the University.

In addition, linking of modules also required extensive communication between staff to ensure that any unnecessary duplication of learning was avoided.



Figure 1. Students from Coventry University in the structural laboratory.

## **Student perspective**

### ***Introduction into Sustainability***

As freshly arriving students at Coventry University we have been introduced to the world of construction by immediate immersion in a studio design project. The brief asked us to create a nursery located on an uneven site with several security risks and thus straight away forced us to become much more flexible in the way we think about buildings and their occupants. Through this initial process, we needed to become more empathetic to the end users of the building (children and their parents, teachers and staff) all of whom have very different needs and require spaces designed especially for them.

This project work, aside from an array of available tutorials has been supplemented by lectures in construction, design and sustainability which allowed us to develop a much more realistic approach to the thought processes behind the designs. Having the chance to design a building of our own straight away has enthused the class and inspired us to perform independent research and work on our projects well beyond the required hours suggested by the brief, both of which are reflected in the rapid progress of the students.

The various design projects took on a much more realistic and hands-on approach outside of the design studios as well. Through a system of lectures prepared by the Engineering and Construction tutors, all Architectural Technology students had the opportunity to experience and participate in lab-based tutorials which involved experiments using real materials in real situations. Through the daylight and concrete laboratories, we have learnt how the light acts within the building and by creating and breaking our own reinforced concrete beam, we could see with our own eyes not only part of the construction process, but also the extent of strength that the materials we specify possess. Finally, the structures laboratory was a real life-based structural calculation of the building resistance to load and pressure that is being exerted on it through its lifetime.

The combination of all these approaches eventually came together in second semester during which the whole class participated in the National TRADA Student Design Competition as part of an experimental, optional module run by the Coventry University. The knowledge of built environment from lectures, ideas for new sustainable solutions from the laboratories and the innovative thought processes from the design studio of the past semester have fruited in the form of competition entries far exceeding those of first year students. Results of this combination of teaching approaches were two finalists in the National Competition with one of them receiving a Highly Commended Award.

### ***Knowledge Application***

In the following year, thanks to the new approach, the students have primed themselves not only in design aspects of the architectural practices, but especially in the sustainability aspect. All Construction students (including Architectural Technology) have taken part in a BREEAM Accredited Graduate scheme which aims to raise awareness of sustainable practices required for real life BREEAM sustainability ratings.

The teaching process at Coventry University felt unique and personally, I would love to see it continued. Combining different modes of teaching and interchanging their styles allows for increased comprehension of the information taught on a much more personal level. I believe that the wide variety of teaching styles is also an inclusive approach to education, ensuring that not just academically gifted students find information easily acquirable.

## **Conclusion**

In the initial response, the student feedback was more rounded and less distinguishing as to certain elements whereas we expected individual elements to be used within different projects. The teaching as a whole acted as an influence on their holistic philosophy rather than the individual parts. This demonstrated how the teaching was successful and that a variety of methods actually increased awareness of sustainability and related issues as a whole.

Whilst this is the aim of the overall outputs of the course, the learning varied within the yeargroup and is a demonstration of how individual modules can come together to influence student understanding of a whole topic. However, the less able students find integration difficult, so we need to look at how the course can increase learning and enthusiasm for all students at all levels.

Communication is essential between staff to continue this approach; therefore staff need to plan integration early and collaborate to ensure that the high level of sustainability teaching is retained for the benefit of the students.

Future potential from this paper is now to further examine the response with an emphasis on individual components and elements within the taught content.



## References

- Bibbings, H and Bieluga, P. (2017). *Enhancing Creativity and Independent Learning of Architectural Technology Students through the use of a Real Life Design Competition Module*. Proceedings of 33<sup>rd</sup> PLEA International Conference 2017 Design to Thrive, Volume 2, July 2-5 2017, Edinburgh, Scotland.
- Bogdanovic, A., Austin, S., and Bibbings, H. (2016). *A comparative case study of online international learning in architecture and construction education* Proceedings of COBRA 2016 – Innovation, Practice and Research in Engineering Education, Sept. 19-22 2016, Toronto, Canada.
- BREEAM 2017. *Why BREEAM* [online] Retrieved from: <http://www.breeam.com/why-breeam>
- Bryan, T. (2005) *Construction technology, analysis and choice*. Oxford: Wiley Blackwell.
- Chudley, R and Greeno, R (2016) *Building Construction Handbook*. London: Routledge
- Iyer, A (2015) *Review of Approaches to Learning adopted by Architecture students I the Coursework of architectural Design* [online]
- Designing buildings 2017. *Design for Deconstruction* [online] Retrieved from: [https://www.designingbuildings.co.uk/wiki/Design\\_for\\_deconstruction](https://www.designingbuildings.co.uk/wiki/Design_for_deconstruction)
- Lucon O., D. Ürge-Vorsatz, A. Zain Ahmed, H. Akbari, P. Bertoldi, L.F. Cabeza, N. Eyre, A. Gadgil, L.D.D. Harvey, Y. Jiang, E. Liphoto, S. Mirasgedis, S. Murakami, J. Parikh, C. Pyke, and M.V. Vilariño, 2014: *Buildings. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA
- Pohl, R (2011) *Building Science: Concepts and Application*. Oxford: Wiley Blackwell.
- Roberts, A (2007) 'Problem Based Learning in Architecture' CEBE Briefing Guide Series 11, p1-4.
- Roberts, A (2007) 'The Link between Research and Teaching in Architecture' *Journal for education in the Built Environment* 2, p1-16. [online] available from [http://ctiweb.cf.ac.uk/jebe/pdf/AndrewRoberts2\(2\).pdf](http://ctiweb.cf.ac.uk/jebe/pdf/AndrewRoberts2(2).pdf) [31<sup>st</sup> March 2017]
- Sinek, S (2011) *Start With Why: How Great Leaders Inspire Everyone to Take Action*. London: Penguin.
- Syed, A (2012) *Advanced Building Technologies for Sustainability*.
- Wilson-Medhurst, S. and Glendinning, I. (2011). Winning hearts and minds: Implementing activity led learning (ALL). In: Kallioinen, O.,(ed) *Proceedings of The Learning by Developing – New Ways to Learn 2009 Conference*, Feb. 12-13 2009, Laurea Publications, Vantaa, Finland, pp304-323.

# Establishing an Approach to Develop a Curriculum of Sustainability in Landscape Architecture in Saudi Arabia

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**Abstract:** Embedding concepts and practices of sustainability into curriculums of higher education programs is a topic gaining momentum. Throughout the different parts of the world attention with varying degree to the subject is increasing. While most of the attention and work has been directed towards the practices and operations of the institutions, a significant effort has been made to address issues relating to curricula, students and pedagogy. This paper aims to review some of the efforts concerning embedding sustainability concepts and practices in the curriculum of higher education programs in general and in the curriculum of professions dealing with the built environment in particular: namely, landscape architecture. A review the landscape architecture program at King Abdulaziz University in Jeddah Saudi Arabia against the findings will then take place to assess the program from the perspective of sustainability. Furthermore, an outline of an approach to review and assess curriculums of design and landscape architecture will be put forth. Finally, discussion and conclusions will be highlighted for the future development of curriculums in the fields of environmental design will be presented.

**Keywords:** Landscape Architecture, Sustainability, Curriculum, Saudi Arabia

## Introduction

Since the 1970's the subject of sustainable development in its many guises and the many arguments surrounding it has increasingly gathered pace and now is being noticed in arguments and policies of development around the world. Through different organizations and initiatives "Sustainability" as a principle is being promoted, encouraged and supported. Perhaps one of the more significant areas organizations and initiatives have concentrated on in their efforts to promote sustainability has been education on all levels in all aspects, and across all disciplines. As the UNESCO (2014) highlight, "There is now an increased recognition at the international policy level that education is essential to the advancement of sustainable development." (p.9).

While education on all levels has received the attention of many on all levels with the United Nations and The Decade of Education for Sustainable Development Initiative (UNESCO, 2014) being at the forefront of these efforts, higher education institutions (universities) receive more attention and focus than other levels of formal education. This could be down to two main reasons as highlighted by Cortese (2003) and Mcmillin & Dyball (2009). One being that higher education institutions will educate and create the new professional that will shape to a large degree society as a whole. "It [higher education] prepares most of the professionals who develop, lead, manage, teach, work in, and influence society's institutions, including the most basic foundation of education" (p.17). The second reason is that most universities and higher education institutions operate and function as a small city (Mcmillin & Dyball, 2009). These two facts have led higher education institutions to formulate amongst themselves organizations and declarations concerned with the advancement of Sustainability as a principle in policy, development, practice and in a few instances a professional degree (Lozano et al, 2015).

The amount of attention and effort exerted by universities towards adopting sustainable development ideals and concepts varies on a global scale (UNESCO, 2014; Lozano et al, 2015). Europe as a region is perhaps leading the global effort in education for

sustainable development (UNESCO, 2014). Education for sustainable development in the middle east has developed in the past decade considerable according to the United Nations (UNESCO, 2014) however, most of the advances have been limited to environmental issues. Issues of economies and society have not been addressed in the region significantly and as such hinder the overall progress of sustainable development and its education.

Saudi Arabia has at present thirty four universities both public and private. In their review, Alshuwaikhat et al, (2016) found that Saudi universities are “still at an early stage” of adopting sustainable development ideals in all areas. They point out that the institutions of the Kingdom have not been involved in global and/or international organizations nor initiatives concerned with the topic. They also point out that unless there is a clear directive and the will to pursue these directives from the top tiers of administration then progress will be slow and the institutions will fall behind global trends.

Most of the literature seems to agree that higher education institutions operate and posses inter-related elements that creates the microcosm within the fabric of a society and can and indeed need to be addressed in the light of sustainability and sustainable development ideals. These elements are perhaps best summarized by Lozano et al, (2015) when they identify eight elements; 1)Institutional Framework 2)Education 3)Research 4)Campus Operations 5)Community Outreach 6)Collaborations with Other Higher Education Institutions 7)On-Campus Life Experiences and 8)Assessment and Reporting. While the mentioned elements represent the possible, upon closer examination higher education institutions and their attention to each element varies greatly.

The majority of higher education institutions around the globe have focused on creating policy and addressing campus operations as a means of contribution towards a more sustainable development (UNESCO, 2014; Lozano et al, 2015; Mcmillin & Dyball 2009; Lidstone et al, 2015). Again regional variations are present with Europe and North America emphasizing education and research in their institutions much more than other regions of the world (UNESCO, 2014; Marcus et al, 2015; Lozano et al, 2015). Very little is known about institutions in the Middle East and in terms of the areas that they are developing for sustainable development promotion.

While this paper is concerned with addressing the methods and/or paradigms by which sustainable concepts and ideals can be embedded in a curriculum of higher education, nevertheless due the nature of sustainability and its interdependencies on other issues and topics, attention maybe drawn to elements identified above.

It is thus the purpose of this paper to examine developments made in the promotion of sustainable development concepts and ideals in higher educational institutions in general and in the design fields more specifically; namely environmental design and landscape architecture. The first part of the paper will review the efforts made in promoting such ideals in curriculums. The second part will provide an over view of the curriculum of landscape architecture in King Abdulaziz University in Jeddah Saudi Arabia. The third part of the paper will address the attributes that may be embedded in a curriculum of a landscape design program in general. This would be followed by the final part of this paper which will be concerned with discussing issues that need addressing and future directions on the subject that need highlighting.

## **Design Education for Sustainable Development**

There is very little work and research available in terms of what should a design education for sustainable development be, what its components are, or indeed how it is to be

delivered to students. While all the literature is in agreement that it is very important for all disciplines be they of design or otherwise embed sustainable ideals and concepts in the curriculums no one seems to identify what is needed. The literature points to three main avenues of concern and discussion. First there is the matter of content in terms of concepts and ideas that are and/or should be included in a curriculum championing sustainable ideals. Second, the distribution and sequencing of the sustainable content throughout the curriculum is a matter of concern. Third, the method of delivering sustainable content to the students has received attention.

### ***Curriculum Content***

As mentioned before the number of works and research in the subject is limited in availability. However, research available seems to point to the fact that the majority of efforts that have attempted to embed sustainable ideals and concepts has been limited to embedding only one of the three pillars that sustainability is built upon, namely environmental issues in the form of resource preservation, emissions control, water retention etc. (O'Byrne, 2014; Marcus, 2015). It seems very little has been embedded in curriculums thus far in terms of economic and social sustainability. While some works point to what is being taught at the moment in environmental design courses and curriculums (Alvarez et al, 2016) very little is being mentioned on what it should incorporate.

The majority if not all agencies, declarations and writing in the subject of education for sustainable development stress the need for the content of any curriculum or subject aiming to develop student understanding of sustainable thoughts and concepts should be interdisciplinary in content (Viegas et al, 2016; Marcus et al, 2015). Furthermore, there are many who suggest that sustainable education should incorporate inherited knowledge of a society and systems to truly be called sustainable (Viega et al, 2016). Meaning that practices and knowledge of a society even if not in a textbook of a discipline should be incorporated into the sustainability education models and curriculums.

While it is not explicitly part of a curriculum, research of staff and students will affect the education of sustainability greatly (O'Byrne et al, 2015; Lozano et al, 2015). Though the research the staff can put forth new issues and concepts to students based on facts and reality. Furthermore, if the research involves the students in a real life situation with its multi faceted concerns, disciplines and issues, the benefits will be amplified and multiplied.

### ***Distribution and Sequencing***

The issue of when to deliver the content of sustainability to students and with what level of complexity is a matter of concern if the information, ideas and concepts are to be beneficial to the student. Lozano & Lozano (2014) in their review of global engineering programs identified four different ways that sustainability is being incorporated to programs.

- a) Existing programs incorporating environmental issues and material on a limited capacity.
- b) A specific course concerned with environmental and sustainable issues within the curriculum.
- c) Sustainability concepts and theory intertwined with disciplinary courses regularly.
- d) A specialization of sustainability in each faculty/discipline.

From the above mentioned types, Lozano & Lozano (2014) point out that the most widespread of the types are "a)" and "b)", while "d)" is very rare. They also point out that the most beneficial of the types is "c)" because it allows students to incorporate sustainable

concepts and theory throughout their learning time in the institution and the subsequent application in their professional life.

Similarly, Altomonte et al, (2012) in reviewing the curriculums of four hundred architecture degrees and training programs in Europe found that sustainability concepts and ideals are being incorporated into programs in one of the following ways.

- a) Parallel : Where sustainable issues and discipline issues run parallel to one another.
- b) Partially Integrated: Where the sustainable issues are integrated partially into the curriculum (some courses)
- c) Fully Integrated: Where the sustainable issues are fully integrated into the curriculum (most courses)
- d) Interactive: Where the issues of sustainability are incorporated into the program by means of student interaction with community or other means
- e) Elective: Where some courses dealing with sustainable issues are offered only as an elective within the curriculum

Again the full integration of sustainable issues and concepts in a program or curriculum is very rare although it offers the best possible format. Thus, there seems to be agreement on the nature of the distribution of the sustainable issues, with full integration into the curriculum as a whole and subjects within. This integration will require a reassessment and rewriting of most of the courses to integrate sustainable concepts related to the subject in the environmental, economic and social capacities.

At what stage of the curriculum theories of sustainability are introduced to the students? While there has been some research addressing this question, policy makers concerned with effective sustainable education stress the need to start at a very early stage of the students' life UNESCO (2014). Sustainability should be worked into the education system as a whole rather than being delayed to university level or beyond. Having said that, the research available into the existing pattern seems to suggest that the a wide spread practice is to deliver the sustainability concepts and issues in short intensive sections of the curriculum usually between the fourth and seventh semester of a design program (Alvarez et al, 2016). Furthermore, the desirable practice of delivering the sustainable ideals and concepts gradually and with more complexity as the student advances throughout the curriculum is very rare and limited. The majority of the programs that do deliver sustainable thought in their curriculum do so in the form of scattered courses and content throughout the curriculum (Alvarez et al, 2016; Altomonte et al, 2012; O'Byrne et al, 2015).

### ***Delivery Method***

If the goal of education for sustainable development is to equip students of design with tools, knowledge and abilities to understand and resolve complex issues and problems; as Marcus et al, (2015) suggest, then the concentration should be on the outputs of the students rather than the inputs of the teachers. While little research has been made in the area of what method is best to deliver a certain topic of sustainability, there seem to be some agreement on what works better. The method of "sequential learning" where by theory is delivered and the implementation and/or use of that theory is deferred to a later time is being questioned as an effective method towards developing sustainable skills or equip students with the required tools to do so (Altomonte et al, 2012). Thus, lecturing students and then expecting them to understand and become creative with the concepts and thoughts of the content to resolve complex problems is a fallacy. "Learning by doing"

on the other hand, is being backed by many as one of the ways forwards to educate the future generations for sustainable development (Marcus et al, 2015; Viegas et al, 2016).

Design studios as an educational method have been proved to deliver to the design student a better understanding of issues and problems and enable them to better resolve a design task taking into consideration many issues and topics. As such, the design studio remains the backbone of most design degrees. There are suggestions that the format of the design studio is an effective method of developing the abilities and skills required for sustainable development (Walker & Seymour, 2007). Indications that the studio format coupled with the involvement of multiple disciplines and/or professionals as well as community will help students in understanding real life problems and issues. In addition, the format also has had a positive effect on improving students organizational and design skills, and their appreciation and respect of team work (Walker & Seymour, 2007).

While the lecture and studio format of teaching are to this moment the most prevalent in design education throughout the world, nonetheless there are some new methods and experiments being carried out throughout the design fields. It is not the scope of this paper to discuss these experiments as in most part they do not relate to the education of sustainability. However, the point that needs stressing is that there must be new approaches and new trials of methods to achieve the best means for delivering concepts of sustainable development especially in the creative fields of environmental design (Cortese, 2003).

### **Landscape Design in King Abdulaziz University**

As part of the school of environmental design in the faculty of engineering of King Abdulaziz University in the city of Jeddah in Saudi Arabia, the department of landscape architecture was established in 1976. Ever since then to date the department has taught the discipline of landscape architecture in the form of a bachelor degree to over 800 graduates. Students currently enrolled in the department are approximately 90 students. The department is now in the process of offering a masters degree in landscape architecture and provided all logistical matters resolved should be offered by autumn 2019.

The department has changed curriculums twice since its establishment and is now in the process of reviewing and updating the existing curriculum. While the subject of landscape architecture and landscape planning is deeply rooted in sustainable thought, namely resource preservation and management, nonetheless the curriculum being taught now does not explicitly reflect that. In the courses being offered the mention of sustainability is very limited. Throughout the curriculum only two of the compulsory courses (Introduction to Environmental Design and Environment and Man) mention sustainability concepts and ideas. Studios only mention sustainability in terms of references and resource materials. Elective courses seem to have the bulk of the sustainability content. With two courses (Advanced Site Planning and Contemporary Directions in Landscape Architecture) incorporating sustainable concepts and ideals into the course outlines and content. Only one elective subject throughout the curriculum is clearly designated to deliver concepts of sustainability (Sustainable Eco-Tourism).

While the content of course files and written description of the courses does not mention sustainability, from over 20 years of experience in the department one can confirm that sustainable concepts and thoughts are being taught to students throughout the curriculum mainly through the urban design and landscape planning studios. Other subjects



may mention some concepts, however the efforts are not organized, specified nor documented.

As such, sustainability as a concept within the curriculum seems to follow the trend of higher education institutions throughout the world with environmental issues taking a lions share of sustainable concerns at the cost of societal and economic concerns. Furthermore, interdisciplinary approaches and incorporation of inherent knowledge of the society/profession is not apparent in the curriculum and is not and being stressed nor pursued. Similarly, research and term projects for students do not stress the need for sustainable concept incorporation and referencing.

The sequence and distribution of the courses within the curriculum that offer sustainable ideas and theory again follow the global trends in that it is scattered in sequence and content. However, there seems to be a pattern in the bachelor landscape program of King Abdulaziz University of offering the majority of the sustainability content in the first year and then again in the last three semesters with very little being offered in the middle section of the curriculum.

In the landscape program for a bachelor degree offered by King Abdulaziz University the preferred or prevalent delivery method of the limited sustainability content embedded in the curriculum seems to be lectures or “sequential learning” as defined earlier. However, in the studios that implicitly deliver sustainability content the delivery system is through the studio or learning by doing.

Thus we can conclude that although sustainability is a valued concept to the department of landscape architecture in King Abdulaziz University, the curriculum in its present description and content does not reflect that. The subject names and areas of the profession they address and tutor in are comparable to most landscape architecture programs in the world. Furthermore, the quality of the program is sufficiently good with more than 50 of the departments graduates (approximately 7% of graduates) obtaining higher degrees in the field from other universities throughout the world. Furthermore, there seems to be no graduated learning plan for sustainability content, with no mention of what concepts of sustainable development being put forth nor the level of complexity of each concept. It is also evident that there is a lack of a coordinated effort to diversify the delivery method of sustainability content in the curriculum. While these issues are serious and need addressing, it is worth mentioning that through the individual efforts of staff and assistants the gaps are being filled implicitly rather than explicitly and within a system. This fact while note worthy, nevertheless is concerning for an academic institution that aspires to be recognized and accredited. It is therefore of great urgency that a system for incorporating concepts and ideals of sustainability in the near future be adopted and utilized towards that goal.

Table 1. Bachelor of Landscape Architecture Program at King Abdulaziz University

Sustainability			Electives
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			Electives
</			

Key

### Explicit Sustainability Content

### Explicit Reference to Sustainability

### Implicit Sustainability Reference

## **Embedding Sustainability in a Landscape Architecture Curriculum**

While there is much work, review and research needs to be done before conclusions can be reached, it is clear that the three main components of concern when it comes to embedding concepts of sustainability in a design curriculum are 1) Content, 2) Distribution and Sequencing and 3) Delivery Method. There has to be a conscious effort to incorporate the principles and concepts of sustainability in curriculums with all three of the pillars of sustainability addressed and their issues tackled. Implicit incorporation of the concepts and principles is not a sustainable practice and all efforts should be planned and documented. Furthermore, the incorporation of interdisciplinary and inherited knowledge to the content of the discipline is vital to ensure sustainable problem solving and solutions. Introduction of concepts and principles of sustainability should be sequenced and the complexity gradually presented to students throughout their program. New methods for the delivery of concepts and principles of sustainability must be put forth and experimented with to achieve greatest assimilation by students. Indications thus far suggest that there is a need to concentrate on formats of delivery similar to design studios for all subjects whether they are technical or theoretical. Principles and concepts based in research, community and real life will have a lasting learning outcome and as such should be encouraged at all times.

Putting all these items together in a visual manner will assist in visualizing and empowering educators to assess and advance sustainability in a curriculum in general and a landscape architecture curriculum in particular. Table 2. Presents an initial attempt at formulating one of these visual aids and tools to assist in this task. Many more tables and aids are required to continue the journey towards education for sustainable development.

Table 2. Assessment of Curriculum Components for Sustainability

											Sustainability Concepts & Principles									Delivery Session									Delivery Method			
											Environmental			Social			Economic			Session/Semester 1	Session/Semester 2	Session/Semester 3	Session/Semester 4	Session/Semester 5	Session/Semester 6	Session/Semester 7	Session/Semester 8	Session/Semester 9	Session/Semester X	Lectures/Presentations	Studio/Workshop	Other
											Level 1	Level 2	Level 3	Level 1	Level 2	Level 3	Level 1	Level 2	Level 3													
Courses & Seminars	Course 1																															
	Course 2																															
	Course 3																															
	Course 4																															
	Course 5																															
	Course X																															
	Seminar 1																															
	Seminar 2																															
	Seminar 3																															
	Seminar 4																															
Seminar X																																
Research & Projects	Research/Project 1																															
	Research/Project 2																															
	Research/Project 3																															
	Research/Project 4																															
Community Outreach	Community Service 1																															
	Community Service 2																															
	Community Service X																															

## Conclusions and Discussion

In this paper the subject of education for sustainable development in a higher education institution in general was discussed and in particular a curriculum for a bachelor program of landscape architecture. While there are some conclusions that one may have reached and assembled concerning the topic, there are many factors and issues that surround the topic and have a direct and indirect effect on it. In concluding, the underscoring of these factors and/or topics will enrich the debate and will be presented.

Educating for sustainability and thriving towards achieving it cannot be achieved by changing curriculums and course content alone. The fact of the matter is that the topic is affected by many spheres and requires a concerted effort. For the sake of simplifying one can identify three main spheres and/or scales that affect and are affected by the topic. First there is the National sphere, where policies are set and visions are realized. It is on this scale that there needs to be a commitment to sustainable development by directing and

supporting institutions, organizations, and members of society that will assist in achieving these goals including education (UNESCO, 2014; Viegas et al, 2016). Without an alignment of policy and plans at the top levels of leadership, systems and institutions at a lower level will function poorly. Second, society as a whole has a major role to play in achieving noble visions and goals. Without a shift from the prevalent attitude of consumption and accumulation and that individual success is independent of the health of communities and the well-being of cultures, sustainable development will always be hindered. The values and behaviors of a society must follow a philosophy of humans being part of nature and our actions will affect the planet and its ecosystems and that the planet resources are limited (Viegas et al, 2016). “The kind of education we need begins with the recognition that the crisis of global ecology is first and foremost a crisis of values, ideas, perspectives, and knowledge, which makes it a crisis *of* education, not *in* education” (Orr, 1994; p.5).

Then there is the third sphere that is most closely related to the topic, that of the institution. Institutions and prevalent education pedagogies need to be changed if we are to move forward in sustainable development (UNESCO, 2014; Marcus et al, 2015). The need for new ways to deliver content in a manner that will equip the future professional to resolve problems in a sustainable manner is urgent. The existing pedagogies in universities depending on the promotion of staff through research and the resistance to change from old methods has delayed experimentation and progress by educators (Cortese, 2003). Furthermore, institutions need to allow their staff space to further train and equip themselves to better educate for sustainable development by getting involved with multiple disciplines, learning inherited knowledge and methods as well as trying new ideas. Engaging the society and especially the youth of the society is perhaps the largest untapped reserve institutions have and as such must be utilized and benefited from. They truly represent the future and the hope of any society and the world. Finally, as Albert Einstein once said, “The significant problems we face cannot be solved at the same level of thinking we used when we created them” (Cortese, 2003; p.16)

## References

- Abubakar, I.R., Al-Shihri, F.S., Ahmed, S.M. (2016) Student’s Assessment of Campus Sustainability at the University of Dammam, Saudi Arabia. *Sustainability*, 8, pp.59-73
- Alshuwaikhat, H.M., Adenle, Y.A., Saghir, B. (2016) Sustainability Assessment of Higher Education Institutions in Saudi Arabia. *Sustainability* 8, pp.750-766
- Altomonte, S., Rutherford, P., Wilson, R. (2012) Mapping the Way Forward: Education for Sustainability in Architecture and Urban Design. *Corporate Social Responsibility and Environmental Management*, 21, pp.143-154
- Alvarez, S.P., Lee, K., Park, J., Rieh, S. (2016) A Comparative Study on Sustainability in Architectural Education in Asia- With a Focus on Professional Degree Curricula. *Sustainability*, 8, pp.290-322
- Cortese, A.D. (2003) The Critical Role of Higher Education in Creating a Sustainable Future. *Planning for Higher Education*, March-May 2003, pp. 15-22
- Huge, J., Block, T., Waas, T., Wright, T., Dahdouh-Guebas, F. (2016). How to Walk The Talk? Developing action for Sustainability in Academic Research. *Journal of Cleaner Production*, 137, pp. 83-92.
- Lidstone, L., Wright, T., Sherren, K. (2015) Canadian STARS-Rated Campus Sustainability Plans: Priorities, Plan Creation and Design. *Sustainability*, 7, pp. 725-746
- Lozano, F.J. and Lozano, R. (2014). Developing the Curriculum for A New Bachelor’s Degree in Engineering for Sustainable Development. *Journal of Cleaner Production*, 64, pp. 136-146
- Lozano, R., Ceulemans, K., Alonso-Almeida, M., Huisinigh, D., Lozano, F.J., Waas, T., Lambrechts, W., Lukman, R., Huge, J. (2015) A Review of Commitment and Implementation of Sustainable Development in Higher Education: Results from a Worldwide Survey. *Journal of Cleaner Production*, 108, pp. 1-18
- Marcus, J., Coops, N.C., Ellis, S., Robinson, J. (2015) Embedding Sustainability Learning Pathways Across the University. *Current Opinion in Environmental Sustainability*, 16, pp.7-13

McMillin, J. and Dyball, R. (2009) Developing a Whole-of-University Approach to Educating for Sustainability: Linking Curriculum, Research and Sustainable Campus Operations. *Journal of Education for Sustainable Development*, 3(1), pp. 55-64

O'Byrne, D., Dripps, W., Nicholas, K.A. (2015) Teaching and Learning Sustainability: An Assessment of the Curriculum Content and Structure of Sustainability Degree Programs in Higher Education. *Sustainable Science*, 10, pp. 43-59

Orr, D. (1994). *Earth in Mind: On Education, Environment, and the Human Prospect*. Washington D.C.: Island Press.

UNESCO, (2014) *Shaping the Future We Want: UN Decade of Education for Sustainable Development Final Report*. Paris: UNESCO.

Viegas, C.V., Bond, A.J., Vaz, C.R., Borchardt, M., Pereira, G.M., Selig, P.M., Varvakis, G. (2016) Critical Attributes of Sustainability in Higher Education: A Categorization from Literature Review. *Journal of Cleaner Production* 126, pp.260-276

Walker, J.B., and Seymour, W. (2008) Utilizing the Design Charrette for Teaching Sustainability. *International Journal of Sustainability in Higher Education*, 9 (2), pp.157-169

# Photography for nourishing visual skills in urban design programme: A Pedagogical module

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**Abstract:** Notwithstanding its regular presence in educational and professional documents, urban design is quite a vague term, practised differently by different groups in different circumstances. One of the most crucial matter is how a city looks and how its spaces are designed, this makes a body-base superimposed on what range of possible sensations can be thought about, evaluated and achieved. Regardless, the concept of urban design as nice images, the urban Architecture of cities comes in accumulative order and creates a visual excitement which gives meaning to the locations concerned. The extent to which students of urban design be schooled the context that can be seen outside the windows. This work focuses on the pedagogical method that documents the public realm by promoting students through learning the photography in urban design programmes to investigate everyday events that form public life. The picturing commuting could be guided by digital photography, archival research and critical thinking analysis. To contrive a kind of change, a module structure may come for the task of urban design as a field of professional practice to have a varied, integrated and transitioning role with different disciplines such as photography for raising the visual skills and boosting the way that students see their external environment. Moreover, the methods and techniques of urban design need to be extended to the unlimited borders of teaching various skills. The results stem from the reports of students' feedback, as well as the course instructor' comments and expert interviews. The conclusion is that urban design, as a visual-aesthetic management, can benefit from a method for module revisited that provides themes for photography to boost the skills that students should gain.

**Keywords:** Photography, urban design, critical thinking, visual thinking, pedagogy

## Introduction

This article discusses the purpose and value of photography in relationship to the design process and understanding urban design. The author bases much of the discussion on her own experiences in teaching both site photography and urban design courses. The author discusses the importance of visual skills. The current research aims to provide a tool to improve students' visual skills in urban design academic disciplines using photography as a technical tool. This photography could be handled as a separate module in the programmes of architecture and urban design or be involved as a subject in splinter courses such as site analysis and communication skills. The question concerns what students should learn in both cases. Generally speaking, the intended learning outcome of urban design courses focus on the common six skills the student should have gained by the end of the course: the knowledge, comprehension, application, analysis, synthesis and critical thinking or the evaluation skills.

## Why should the student learn photography within urban design education?

### *Evidence from literature*

Urban design is the art of (re)making dynamic public spaces into places promoting human intercommunication, economic exchange and well-being (Abussada 2015). This interdisciplinary field depends on collaboration among various professions concerned with people and the building environment. The intention is to transition streets and backyards into a series of places where such activities take place. In addition to creating places where

people feel safe, are aesthetically pleasing or allow ease of movement throughout a space, urban designers consider the relations between the natural environment and the constructed environment to create successful cities and urban centres. Therefore, the design process is based on the human needs of people who will use the space concerned. Consequently, the designer must create the space from their perspectives to support the sense of community. The beginning of urban design in Harvard University in the mid-1950s was an academic discipline within post-graduate studies. The latter acts as both an academic discipline and a field of profession.

The revised process of developing an educational curriculum depends on scholars and practices driving the knowledge base, the discernment of what urban design is and the intended outcomes that will be applied to the local community, indeed, ‘... urban design education should be based on an understanding of what are seen to be successful, robust places, as well as the multiplier and side-effects any design has on its surroundings’ (Lang 2016, 563). The quaternion comes from how the curriculum of urban design programme boosts the student in regard to what they see. Moreover, Cuthbert (2001), Lang (2005) (2016, 562) and others (Pittas and Ferebee 1982), (Lara and Evans-Cowley 2016) have explained the importance of learning the urban design process through making the built environment functions and to whom through the knowledge-based and problem-solving or project-based learning approach should be directed. These approaches focus on the case studies and challenges that exist in cities. The advantage of using the problem-solving approach based on the available case studies have the potential to learn the holistic and significant characteristics of authentic life circumstances (Yin 2003).

Cuthbert (2001, 304) has rephrased the query that has been widely raised in literature from ‘What are the core skills that all urban designers should have to practice efficiently’ to ‘Which generic problems exist in the urban design, and what contextually specific knowledge is required for understanding them?’ When combined with socio-culture, linguistic, religious and other norms to reach future spatial scenarios (Moudon 2016), it becomes evident which knowledge is necessary and which is restrained or otherwise eliminated from traditional urban design modules. In the present, in some Arabic cities, the problem of chaos is distinguished by persons and users who compare the differences in another context, and some had become familiar with it to the level of convenience. For those students in architecture schools with chaos around, he/she can criticise the badness regarding being good because this is the only scene getting used to in their daily lives. In this case, reclaiming visual perception becomes a core skill for students of architecture and urban designers who grew up in a city of chaos.

Urban design could be taught in many ways, but should focus on two going-together streams and ends regarding city prosperity: one track is for the theory, and the other is for methods and techniques. Besides, Salama (2015, 9) mentions ‘...that many recent graduates of architecture schools have been inadequately trained to work in the real world’, but the question comes to the skills gained during his/her undergraduate studies. The current research will focus on the second stream which can be separated from the first one. The methods used include a broad range of subjects, from approaches and person-environment relations to communication routines including these of digital media (i.e. photography). Reading and documenting a photograph or other visual images plays a major role in raising the visual skills that the city designers should have (Banks 2001, 11). The literature describes approaches to reading photographs: ‘looking through’, ‘looking at’ and ‘looking behind’ (Collier and Collier 1986) (Wright 2016). In looking at the visionary objects,



Julia Gospodarou (2014) and Schulz (2015) answer what makes a good message in the photo as the connection with the subject. If the designer gains this connection with the city objects using the meditate while taking a photo, he/she can read, elicit the art of relationship between things and criticise the good and bad in things around them. Further, Cullen (1971) presents the concept of serial vision in his book *The Concise Townscape* through the approach of sensory of photo-elicited. Documenting the concept of serial vision tends to interpret the dynamic nature of the user's experience and is considered one of the foremost objectives of urban designer. Those students and professionals who present similar analysis to the way Cullen did in the plan of Westminster, Ipswich and Oxford think more clearly about the art of relationship of what is here and there (Lim, Azevedo and Cooper 2016, 255), and the change in the view while moving around on the street and in public places.

In another context raised by Frey (2007, 339-340) in *The Urban Design Reader* edited by Michael Larice and Elizabeth Macdonald, visual skills could be taught and seen in a good image with a chance to be creative and an aesthetically pleasing environment. Generally, literature tells us six main skills (Figure 1), starting with understanding, comprehensive skills and ending with evaluation and transferable skills. The visual skills in most modules are not found or listed under the transferable skills. Berret et al. mention that knowledge has two domains regarding outcome: self and action. In the case of current research, the action is to create or develop a good city in return for what the student of urban design will learn? And what visual skills will boost the good city? (Figure 2)

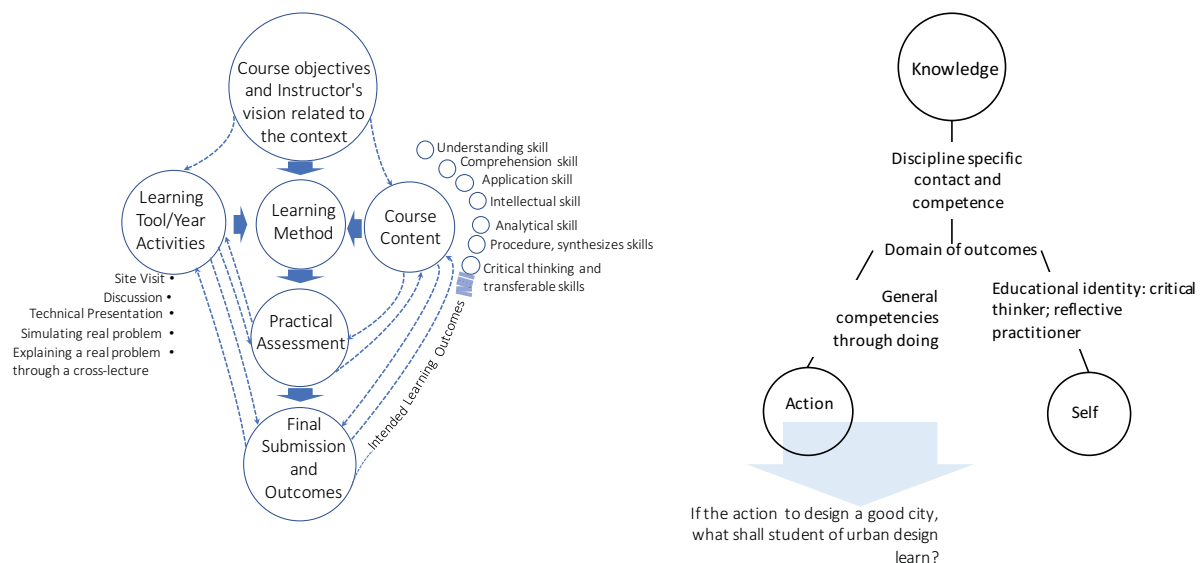


Figure 1. Skills that should be embedded in urban design module/programmes

Philip Thiel (1962), (Crowe and Hurtt 1986), (Arnheim 1997) and (Jiménez-Montano and Ortiz-Rivera 2014) go on to show how a programme in visual education using other graphics processes (i.e. photography) may be developed—in sequence and in-depth—to supply the unique preparation that unique profession demands among urban design professions. Bauhaus formed a consistent method of teaching space in art by linking the visual language to John Ruskin's prototype of the innocent eye (Ruskin 1885) (Varnelis 1998). The concept of the 'active vision' introduced by Colin Ware (2008) profound the implications for design and the visual education through boosting the process of visual

thinking. In this context, Ware (2008, X) figures out the visual thinking as ‘a kind of dance with the environment with some information stored internally.’ Subsequently, Colin Rowe and Robert Slutzky (1976) interpreted, in architectural terms, the idea of a language of space; this served to reinforce the discipline when architecture seemed to lose its meaning in the sixties.

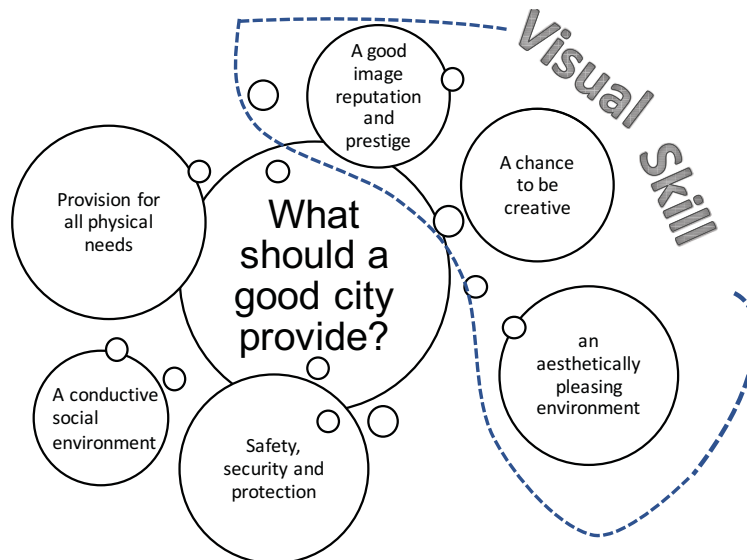


Figure 2. The visual skill that could boost a good city

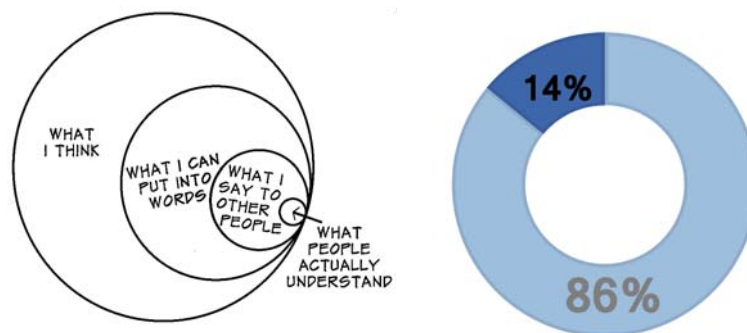
Therefore, visual education should hold a vital position next to design itself, in the curriculum of any school of architecture. To ensure effectiveness, this must be increased ahead of the time-extolled exercises of freehand sketching and rendering. Generally, in architecture school and urban design programmes, undergrads and post-graduate students learn two things: first, how to think architecturally within a given context; second, how to apply your architectural thinking based on the conducive social environment and as a specific thing that should be focused on visual skill. Visual skill is what distinguishes architecture from other disciplines; specifically, the visual ability could be gained and tracked in site observation and site analysis, which may need to be taught at the university per specific rules.

### ***Evidence from urban design modules in the universities***

The problem in Egypt arises because the architectural programmes do not focus on the visual skill as essential in the design process. The prove could be tracked in the curricula in most distinguished universities, with Cairo being one example. These curricula only focus on the visual skill of drawing through the courses addressed; the course regularly teaches addresses as ‘Freehand Drawing and Visual Training’ without reflection of the outside environment that student lives through or see per his or her daily trip. In other words, the main objective of all instructors in the architecture programme is to raise the students’ intellectual skills with a missing part of how to criticise the current scheme in their built environment. In Harvard University—in the Department of Visual and Environmental Studies—students are studying photography and studio art; Introduction to Still Photography, Slow Photography (formerly Conceptual Strategies in Photography) and Expanded Visual Thinking. Department of History of Art and Architecture, a notable course, Islam and Image, addresses the relationship between the Islamic religion and photography

that ‘looks at the broad scope of two-dimensional images produced throughout the Islamic lands’, Twentieth Century Photography (Faculty of Arts & Sciences 2017), photography, race and citizenship (Lewis 2017). Further, some researchers conclude the importance of the photograph as supporting tools raise the visual thinking skills in Architectural education (Kress and van Leeuwen 1996), (Toka, Kaplanb and Tanelia 2010).

In the case of Egyptian students, a question posed to students about the skills they would like to develop, asking them to state them in order of importance. The answers the researcher received were percussive, since visual skills were not listed among the students’ answers. Further, a diagram had shown to them by the difference between what one thinks and what people actually understand, with 86% percent of students agreeing with this description (Figure 3). Generally, the leader of knowledge of urban design has stages. Actually, their answer regarding the previous interview, as well as being stacked with these students in several courses, shows that most of them are at the 1<sup>st</sup> and the 2<sup>nd</sup> stages of knowledge (Figure 4). Furthermore, if they have the ability to raise their skills to reach the 3<sup>rd</sup> stage (‘action’, for instance), there will be a gap linking gained knowledge to professional practice and the labour market. Moreover, many individuals, as well as architects, need to draw while they talk in order to express their ideas. They need to make a mark on paper as they state a point; they build up a diagram as they develop their argument, take a photo to document a place, event or even express idea that could be applied similarly in his/her project. Consequently, most architecture courses should focus on things such as site photography, and the intended learning outcome of photography courses that enhance student’s visual skill should be those skills that they should acquire before graduating.



**Figure 3.** On the left, the gap between what students think and what other perceive the idea. In the right, the percentage of agree/disagree about this matter.

## **Site Photography module in urban design programme: A case from Egyptian university**

### ***Course structure and indented learning outcomes***

In 2013 the course Site Photography and Documentation (UPL 153) was designed and developed by the present author in the programme Landscape Architecture at Faculty of Engineering, Ain Shams University, Cairo. This module is designed for students at the first level of their Architectural learning. Based on the questions raised, in order to design a state-of-the-art curriculum map, could have five main stages of learned lessons that are covered in different periods of time (

Figure 5). For instance, camera shooting is covered in six weeks and the rest in six weeks; the remaining time is for linking the knowledge gained to other disciplines and practising on the critical thinking. The course also has three submissions and follow-ups with pre-given criteria. Documenting the photos, and in what field they are to be used, is presented in

designing a poster or book cover using the photos students have captured as well as to organise photo session events. The photos are intended for exhibits during the last three years to document the theme of Our vision—Our Place, Known and Unknown Places, A Voice for Children in Design Process and the final one in Summer 2017: The Food in Built Environment (Figure 6).

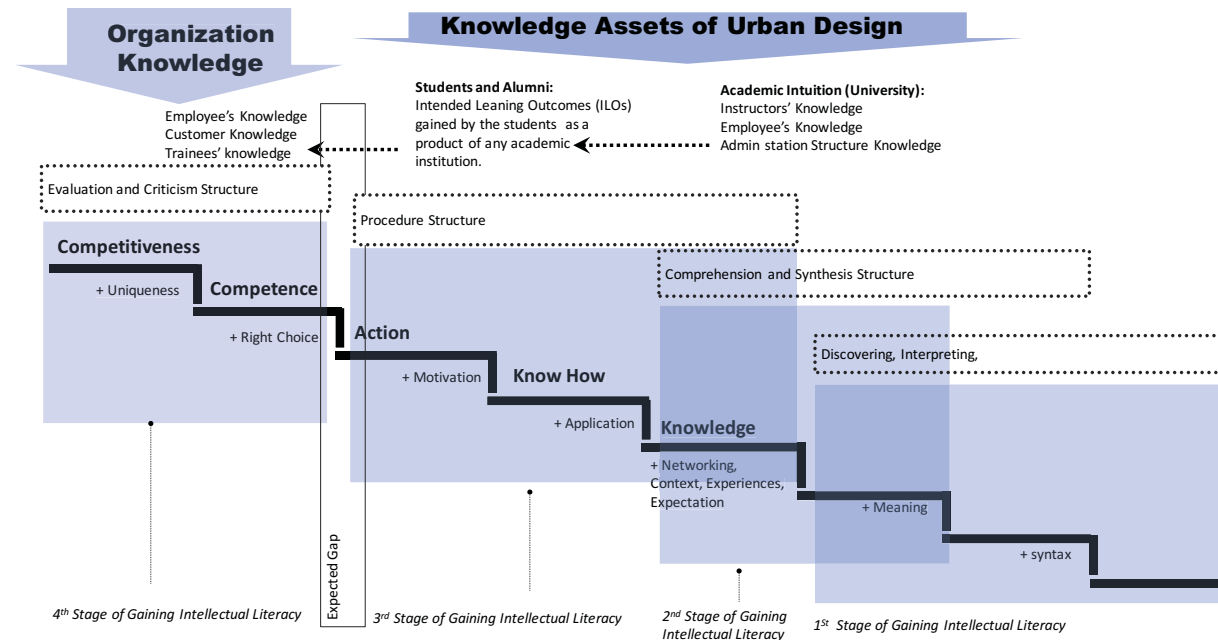


Figure 4. The leader of knowledge

### A method for module revisited

The module of 'Site Photography and Documentation' has been offered throughout the four years of teaching within the Landscape Architecture programme for undergraduate studies as a pre-request module for urban design. The current research tries to revisit and analyse the progress of the course through the instructor's reports, student feedback and experts' interviews, as well as per external referees of the course itself.

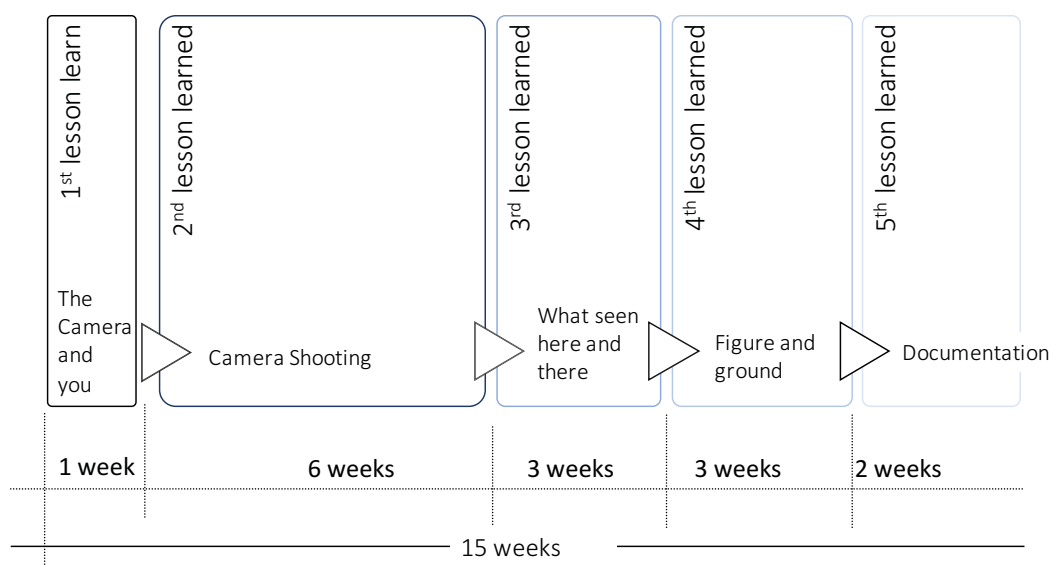


Figure 5. The five stages of the course structure



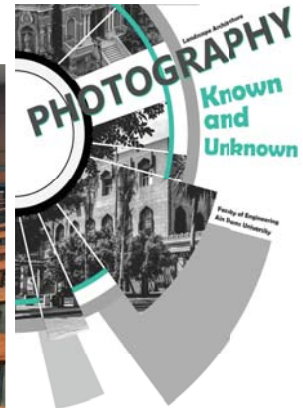
Spring 2015

## 5<sup>th</sup> lesson learned

Documenting the photos  
and in what field they  
will be used



Spring 2017



Spring 2016

Figure 6. Some activities that take places in the module as the 5<sup>th</sup> lesson learned through the documenting process. Source: the author

The course report is one resource for course improvement. Analysing the instructor's reports during the course offered provides both summative information for decisions relating to curricular development and formative information for instructional improvement at the academic instructions tenure and promotion in higher ranks. The results of this analysis will report the core skills of understating, intellectual and practical skills regarding the students' attitude. The students' feedback was collected by the questionnaire<sup>1</sup> through 550 participants who completed the course during the last four years and six times of course offered. Aside from the understanding, intellectual and practical skills, the students were interviewed about the transferable skills that support the critical thinking, creative thinking, communication and collaboration. Excerpts were selected for the interview based on being early career professions practising urban design or architecture using the digital photography techniques. In order to have a photography module in Urban Design Programme, the questions that the instructor asked needed an explicit answer. The issue is asked to experts within the tutorial were:

- What do you want students to know and be able to do by the end of the programme/course?
- How will the students be able to use this learning? Doing what? In what context?
- What level you are aiming for?
- What will the student need to do to demonstrate if and how well they have achieved these outcomes?
- If someone were to ask the students what they have learnt in this programme/course, how would you like them to answer?

<sup>1</sup> <https://www.surveymonkey.com/r/5M6S5XT>



### ***Discussion and findings: What learning skills should the student of urban design have?***

The semi-structured interview with academic lecturers gives some remarks in term of intended learning outcomes of the Photography module and the reflection of these findings on other modules. Regarding this matter, the importance of the module is found in auditing the way students should see objects within their constructed environment. Furthermore, most interviewees coincide that the module can help them in regard to interpreting and when thinking critically about the composition of objects. Alongside this, some of the respondents added that learning photography contributes in captured screenshots in digital media (i.e. 3D max). By contrast, older professors mentioned that the module was not essential for raising the visual skills; drawings, tracing and depicting, picturing, tracing object as the effective method that can increase curiosity and imagination skills. They also added that there was no need to have this course in architecture or even urban design programmes; a one-week workshop will enable the students to learn how to take good photos and document them as well.

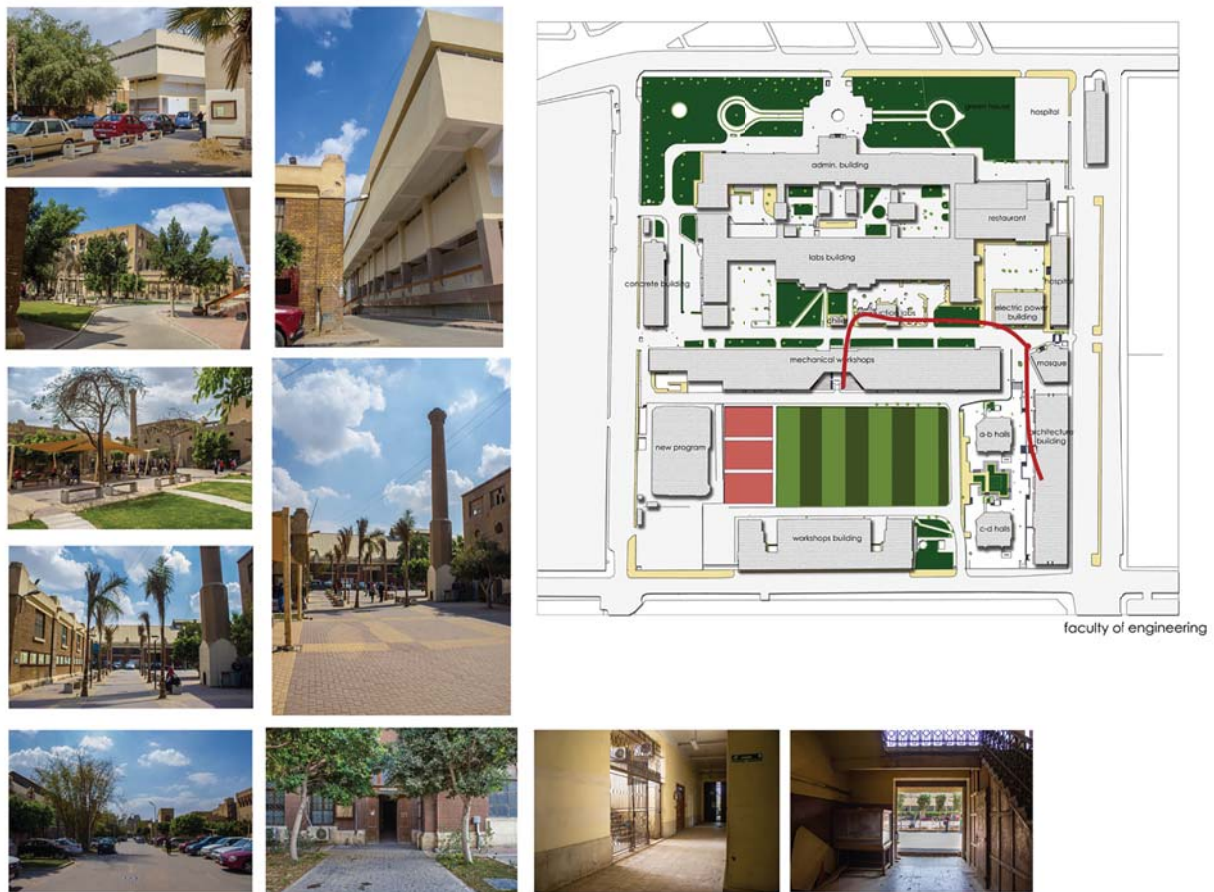


Figure 7. Some of the applications of serial vision through the captured photos in documenting process which helps in linking the module with other technique of site analysis. Source: The students of Spring 2016 class of the module.

The results of students' responses to the questionnaire show relevant answers to be near to the global benchmark concerning the following questions: 'How likely is it you would recommend this module to a friend or colleague?' The choices of the expected answer range between 0–10 from 'not at all likely' to 'extremely likely'. In Figure 8, the response

comes reaching the net promoter score (38) to the global benchmark (40). This is reflected in how relevant topics are discussed in the course regarding the expected career, yielding scores of 36.46% for 'very relevant', 23.96% for 'extremely relevant' and 6.25% for 'not at all relevant'. For the question 'As one of the intended learning outcomes is seeing objects differently, how reachable was this goal?', the responses varied between 'extremely reaching' (45.92%) and 'not at all reachable' (3.06%).

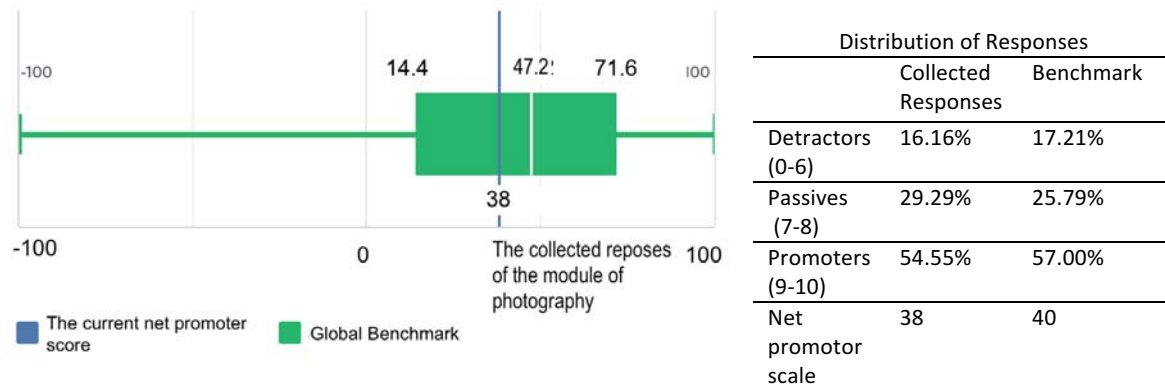


Figure 8. The response to 'How likely is it you would recommend this module to a friend or colleague?' Source: the author based on the data powered by SurveyMonkey

The arrangement of the topics that had been discussed in the module reflected their importance, from their side, of the tips that should summarise the issue explained to them followed by the camera technique and shooting. The link from photography to other disciplines comes in the latest stages, although without this link students could not be able to use gained skills in further, advanced module he/she may practice such as site analysis, urban design and/or 3D max. In particular, Photo-participation in an Event or Workshop was arranged low stage. Figure 9 gives a score out of 10 for the recommended topics with priority given to both the expert and architecture students. Although some of elder professors thought the importance of the module to be as an elective course or to be taught as a one-week workshop rather than a core course.

Furthermore, there was a minor distance between the respondents of professional participants and the students of the earlier level of the module. Aside from understanding, practical and intellectual skills, the transferable skills gained by the end of the course are shown in Figure 10. Curiosity, imaginably, visual and arguing skills have a high percentage among other skills gained per the module. Notably, some respondents' answers were gained are out of context and are not relevant to what had happened regarding the module's teaching policy (i.e. the presentation techniques and all listed skills).

The responses of one-ended-questions open several remarks related to the appealing of the course, the importance of indented learning outcomes, having tangible module outcomes and theoretical and background education regarding being a photographer rather than an architect. Some respondents made it clear that they could not understand some questions and terms (i.e. visual, agility and critical thinking skill,) and said that some words were fuzzy (i.e. initiative and entrepreneurialism). Some could not determine the importance of the intended skills. Regarding this, a student said: 'This is my first level in architecture, I have no link to what had been taken in other courses. Maybe later, I will have a chance to find out the correlation and interference between disciplines. Furthermore, it is good to discover some places and sites that I visit regularly, but I could not

recognise its beauty or ugliness.’ The critical thinking skill is noticed throw their response regarding the ‘assessing method should be more specified’, said one of them. In regard to recommending the course to others, one response mentioned it was ‘not easy to recommend the course to a friend unless he/she is an architect. The topics raised most are not related to pure photography; architecture photography.’

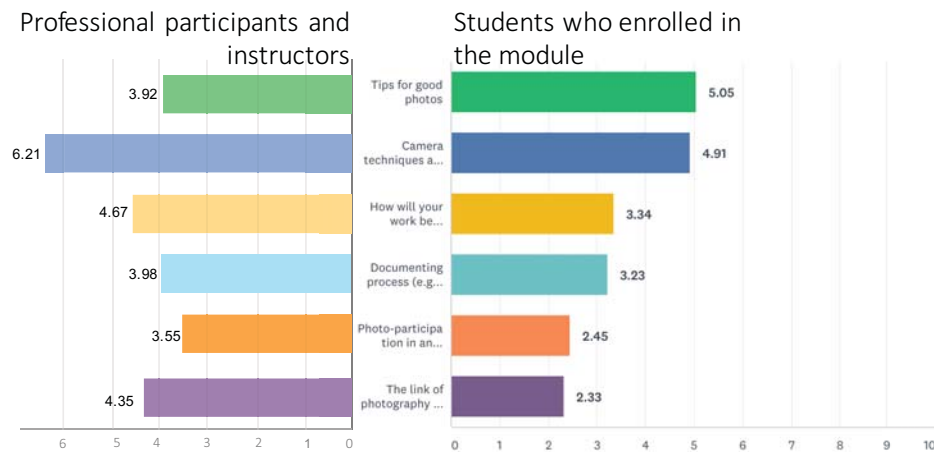


Figure 9. The response of both the professional practice and the student enrolled in the course to the issue Arrange the following topics based on importance. Source: the author

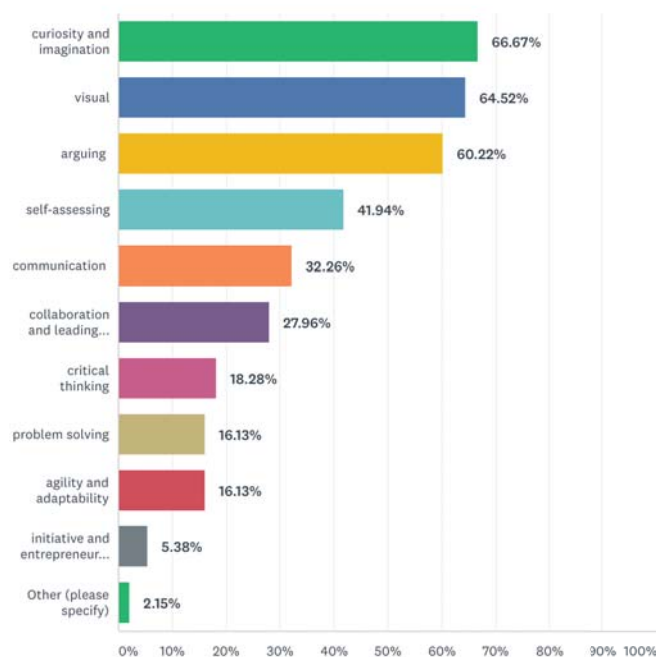


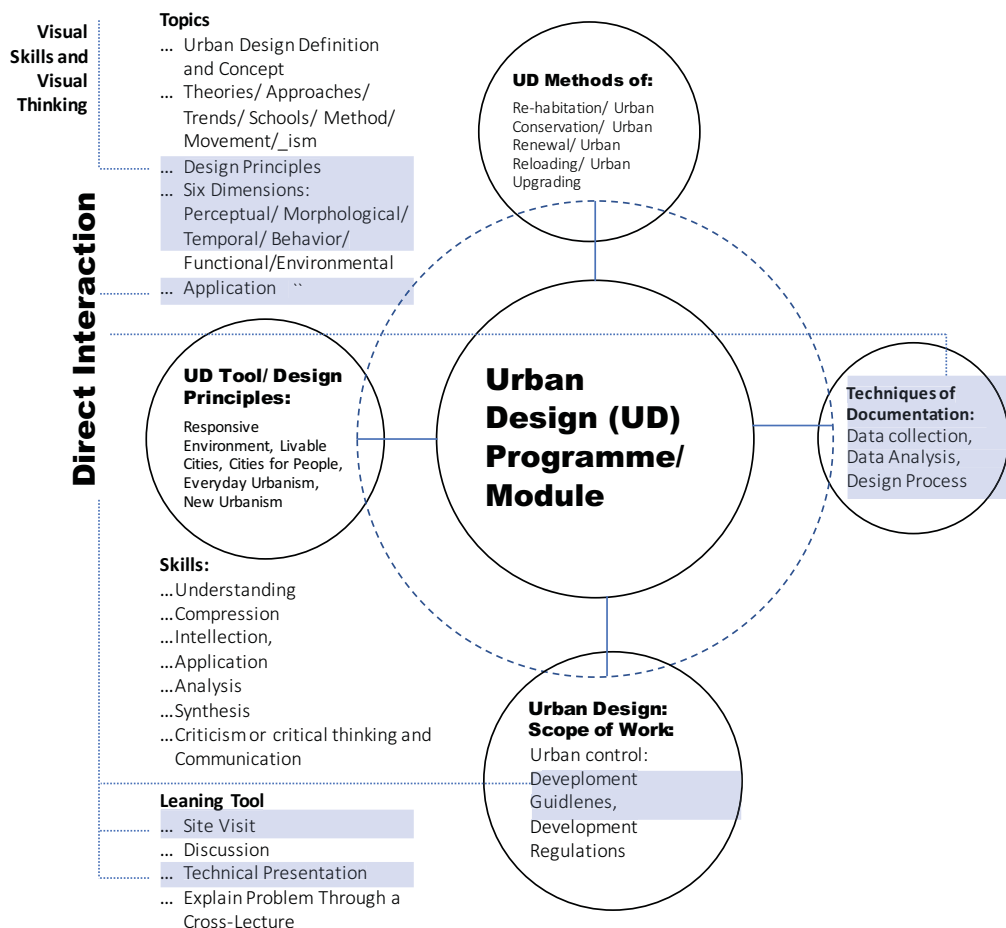
Figure 10. The arrangement of skills the student should gain. Source: the author

## Conclusion

‘Professors, students and practitioners often are amateur photographers of cities and planning. All of us could produce not only images but documents of long-term value’ (Krieger 2011, 317). In architecture and urban studies, the matter is not how we can see things, rather it is how we perceive them in context and the vision of documenting them perfectly. The necessities of photographers and urban designer unavoidably collide in the world of architectural photography. Though both professions qualify as art professions,



designers and photographers manage to see things very differently. Urban designer form, three-dimensional spaces, while a photographer is concerned with only two dimensions and in some case the object, not the background. Architects like to see photos that contain a maximum of visual information and that convey the dimensional and tactile effects of the structure in a pure, unadulterated fashion. A photographer's interpretation can use framing and composition to produce a very different impression of the same building—an idea that can be seen by the architect to have a negative effect on the informational nature of the image. The point is, every architectural photo depicts an argument that can—from urban designer's point of view—compromise the authenticity and informational nature of built environment appearance. This contradiction makes it especially challenging for an architectural photographer to satisfy both individual and parties with a single photo. Within the module of photography and in reference to Urban Design programme/module comprised of the methods, tools and techniques and visual skills, visual skill could be embedded in the site visit, data collection, data analysis and so and so fourth through short-, medium- and long-term interaction (Figure 11). The main four C's and one V: critical thinking, creative thinking, communicating, collaborating and visual thinking, can contribute in the vague in urban design module and even the programme itself.



**Figure 11.** The indented learning outcomes that the visual skills could be impeded. Source: the author based on (Elshater 2014, 58)

## References

Abussada, G. Hisham. 2015. *The Art of the City: Refutation of intellectual discourse as an introductory to knowledge enlightenment*. South Africa: Partridge Africa.

- Arnheim, Rudolf. 1997. *Visual Thinking*. California: University of California Press.
- Banks, Marcus. 2001. *Visual Methods in Social Research*. London: Sage Publication Ltd.
- Collier, John, and Malcolm Collier. 1986. *Visual Anthropology: Photography as a research method*. New Mexico City: University of New Mexico Press.
- Crowe, Norman A., and Steven W. Hurtt. 1986. "Visual Notes and the Acquisition of Architectural Knowledge." *Journal of Architectural Education* (Routledge) 39 (3): 6-16.
- Cullen, Gordon. 1971. *The concise townscape*. Oxford: Elsevier Ltd: Architectural Press and Elsevier Ltd.
- Cuthbert, A. 2001. "Going global: Relexivity and contextualism in urban design education." *Journal of Urban Design* (Routledge) 6 (3): 297-316.
- Elshater, Abeer. 2014. "Prosperity of Thought versus retreat of Application: A Comprehensive Approach in Urban Design Teaching." *International Journal of Architectural Research, IJAR* (ArchNet-IJAR) 8: 45-63.
- Faculty of Arts & Sciences. 2017. "Twentieth Century Photography." Accessed June 1, 2017. <https://courses.my.harvard.edu/psp/courses/>.
- Frey, Hildebrand. 2007. "Compact, decentralised or what? The sustainable city debate." In *Urban Design Reader*, by Michael Larice and Elizabeth Macdonald, 328-343. London: Routledge.
- Jelaar, Joel Tjint, and Julia Gospondarou. 2014. *From basic to fine Art: Black and white photography architecture and beyond*. Athens: [www.envisionography.com](http://www.envisionography.com).
- Jiménez-Montano M., Ortiz-Rivera L. 2014. "Development of Visual Skills: Digital Photography as a Tool for Research and Teaching in Architectural Education." European Conference on Information Literacy: Information Literacy. Lifelong Learning and Digital Citizenship in the 21st Century. Springer. 407-416.
- Krieger, Martin H. 2011. "Lessons from Charles Marville—Preserving Detail in Media Documentation of Cities, Studying that Detail in Urban Research." *Journal of Planning Education and Research* (Sage) 31 (2): 217–219.
- Lang, Jon. 2016. "Notes on designing educational programmes for urban design." *Journal of Urban Design* (Routledge) 21 (5): 561–563.
- . 2005. *Urban Design: A Typology of Procedures and Products - Illustrated with 50 Case-Studies*. Oxford: Architectural Press.
- Lara, Jesus J., and Jennifer S. Evans-Cowley. 2016. "Internationalizing urban design education." *Journal of Urban Design* (Routledge) 21 (5): 564–566.
- Lewis, Sarah. 2017. "Photography, Race, and Citizenship." *Faculty of History of Art & Architecture*. <https://courses.my.harvard.edu/psp/courses/>.
- Lim, Regina Mapua, Laura Novo de Azevedo, and Jon Cooper. 2016. "Embracing the conceptual shift on new ways of experiencing the city and learning urban design: pedagogical methods and digital technologies." *Journal of Urban Design* (Routledge) 21 (5): 638-660.
- Moudon, Anne Vernez. 2016. "An alternative pedagogic model for doctoral research in urban design." *Journal of Urban Design* (Routledge) 21 (5): 690–701.
- Pittas, Michael, and Ann Ferebee. 1982. *Urban Design Educators' Retreat*. Institute for Urban Design and Ross Pub.
- Rowe, Colin, and Robert Slutzky. 1976. "Transparency: Literal and Phenomenal." In *The mathematics of the ideal villa and other essays*, 45-54. Cambridge: MIT Press.
- Ruskin, John. 1885. *The Elements of Drawing in Three Lessons to Beginners*. New York: John Wiley and Sons.
- Salama, Ashraf M. 2015. *Spatial Design Education: New Directions for Pedagogy in Architecture and Beyond*. Surrey, England: Ashgate Publishing Limited.
- Schulz, Adrian. 2015. *Architectural Photography: Composition, Capture, and Digital Image Processing*. Edited by Gerhard Rossbach. CA: Rocky Nook Inc.
- Thiel, Philip. 1962. "Unique Profession, Unique Preparation." *Journal of Architectural Education* (Routledge) 17 (1): 8-13.
- Toka, Selay Yurtkuran, Ian Kaplanb, and Yavuz Tanelia. 2010. "Photography in architectural education: A tool for assessing social aspects of the built environment ." *Procedia Social and Behavioral Sciences*, 2583–2588.
- Varnelis, Kazys. 1998. "The Education of the Innocent Eye." *Journal of Architectural Education* (Routledge) 51 (4): 212-223.
- Ware, Colin. 2008. *Visual Thinking for Design*. Edited by Mary James. London: Elsevier.
- Wright, Terence. 2016. *The Photography Handbook (Media Practice)*. Edited by 3<sup>rd</sup> Edition. New York: Routledge.
- Yin, R. K. 2003. *Case Study Research: Design and Methods*. Thousand Oaks: Sage Publications.

# Building Capacity for Sustainable Development of the Built Environment in Egypt: Challenges and Opportunities

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## Abstract:

The Sustainable Development Strategy (SDS) for Egypt has been recently introduced with three main goals to be achieved by 2030; economic development, competitiveness of markets and human capital. Hence, education for sustainable development in the Egyptian educational system is paramount. The building industry is considered one of the largest industries in Egypt, contributing with 34 per cent of the total National Gross Income, requires strategic planning to ensure principles of sustainability are learnt and applied in this key and dynamic sector. Building Capacity for Sustainable Development of the Built Environment (BC-SDBE) project proposes a viable framework for achieving sustainability in the built environment supported by proactive participation of stakeholders in built-environment-related disciplines. This is in the form of stakeholder workshops and a skills gap survey to outline the specific needs and demands in the construction labour market and the roadmap to achieve SDS objectives.

The paper presents the findings from the stakeholders' skills-gap survey undertaken to identify the current gaps in the construction sector in Egypt concerning sustainability. The survey questionnaire distributed to professionals, academics, researchers and students in the construction sector aims to gauge the level of education and training achieved at pre and post professional levels. The results are presented and discussed in the first stakeholders' consultation workshop where academics, professionals and researchers in the built environment were invited to contribute. The outcome is to develop in-depth understanding of opportunities and challenges for the integration of sustainability in the built environment in education and practice in Egypt.

**Keywords:** Education for Sustainability, Sustainable development, Education, Training, Egypt

## Introduction and context

In the context of global carbon dioxide emissions, the USA and China represent 17 and 21.9 per cent respectively while Egypt represents only 0.65 per cent with 2.7 metric tons per capita (World Bank, 2014). Hence, as a minor contributor to global carbon emissions, any initiatives taken to reduce Egypt's emissions can only have significant effect at national level, but hardly any global impact. In order to effectively reduce carbon emissions, the Egyptian government recently launched the "Sustainable Development Strategy (SDS): Egypt's vision 2030" which targets three main goals; economic development, competitiveness of markets and human capital (SDS Egypt 2030, 2016). Hence, sustainable development is a fundamental pillar for the socio-economic welfare of Egypt; as a developing country. However, the rapid growth of the country limits the resources required to meet its national demands, particularly in the building sector. The building industry is considered the largest resource-consuming sector that has direct impact on Egypt's economic stability and growth, in which its share in the total National Gross Income is nearly 8 per cent (Construction Review, 2015). Statistics indicate that the manpower involved in the building industry sector represents over 11 per cent of the total Egyptian workforce (Central Agency for Public Mobilisation and Statistics (CAPMAS), 2014). This requires strategic planning to ensure principles of sustainability are indeed learnt and applied in this vital sector.

Amongst the mega projects that the Egyptian Government aims to complete in the short and medium terms are: Suez Canal axis development project, The New Administrative Capital, The 4 Million Acres development project, Sinai Corporation for Development and

Investment, Northwest Coast Development Project, “Golden Triangle” Project for Mineral Resources, New Development Axis, 30 June Axis, and New Galala City, The fourth and fifth phases of the underground project, and Building One Million Social Housing Units (SDS Egypt 2030, 2016). As the country is striving for sustainable development to improve the living and working conditions of its population in a consistent manner, the SDS aims to promote human resources via two main axes; education and health.

Regrettably, professional training and education in sustainable development in Egypt is currently limited; compared to the rapid progress and substantial awareness in developed countries. Moreover, there is significant lack of training programmes and curricula that coordinate between stakeholders; researchers, academics and practitioners that embed holistic sustainable development at various scales of the built environment; buildings, neighbourhoods, cities and regions. The SDS identifies various challenges for effective technical education and training. Of those challenges; the necessity of effective integration of technical education, vocational training and other educational forms (MOPMAR, 2016). Hence, the transformation of the Egyptian educational system to adopt the approach of building capacity as the cornerstone of sustainable development would be key for the Egyptian national plans to be successfully delivered. Academic and research institutions should also aim to provide pertinent education and training to stakeholders involved by embedding ‘sustainability’ in formal and informal education and training.

### ***Education for sustainability (EfS)***

The term ‘sustainability’ has had many interpretations and definitions, dependent on the context at which it is being defined. It has been widely advocated that the three main pillars of sustainability are economy, society and environment. In the built environment context, Altomonte, et. al (2014) find that debates concerning social and economic sustainability have at many instances dominated over environmental sustainability when considering energy efficiency, resource conservation, etc. making it more challenging to define the ethos of sustainable design in this context. They find that educating for sustainability is not only about the content of the curricula taught, but is ultimately about the approach of integrating sustainability to inform the design process discourse (Altomonte, Rutherford, & Wilson, 2014). Hence, the challenge ahead of educators and professionals in the built environment is twofold; first, for them to promote and develop a clear understanding of social, economic and environmental sustainability in the context of construction, and second; to help develop a deeper understanding of their discrete role in developing others’ attitudes related to socio-economic and environmental issues in that context (Murray & Cotgrave, 2007).

Moreover, the inter-related pillars of sustainability augment the complexity of achieving successful education for sustainability initiatives, concerning the content delivered and the methods of delivery. Some curricula may employ surface learning approaches that may focus only on knowledge acquisition (i.e. transmissive learning), without necessarily developing critical and reflective understanding (Altomonte, Rutherford, & Wilson, 2014). Education for sustainability should, in essence, adopt deep learning approaches based on pedagogies that combine knowledge acquisition with critical thinking and problem solving techniques (i.e. transformative learning), in order to ensure creative and relevant solutions are developed in response to real life scenarios. Cotton and Winter (2010) support a necessary paradigm shift from transmissive to transformative for good practice sustainability education. Hence, innovative pedagogical methods, course structures and

content, learning outcomes and methods of delivery should facilitate deep learning and develop problem solving skills. Moreover, EfS requires educators in Egypt to adopt and champion a change in attitude from perceiving sustainability education as an 'add-on' to "a unique educational concept that challenges conventional modes of education and requires new methods of integrative learning" (Barth & Michelsen, 2013, p. 106).

This could be achieved by means of effective stakeholder participation which promotes grass roots interest within the learning community that would work in tandem with top-down approaches (e.g. SDS policy in Egypt). It has been advocated by EDUCATE that a simultaneous bottom-up and top-down approach should be adopted to support the successful implementation of sustainability and energy efficiency in education and practice of design (Altomonte, 2012). The UNESCO's Global Education Monitoring Report (2016) asserts that: "The private sector, civil society, multiple sectors of government activity and international actors should work together to fund various facets of education, since education matters for all aspects of sustainable development" (UNESCO, 2016). Some initiatives that seek to achieve EfS have shown that bottom-up approaches and collective efforts play a significant role where each individual shows commitment to their specific field of responsibility where the policy framework may be decentralised (Dlouha & Pospíšilova, 2017).

According to Sterling (2001); in the context of higher education (HE), sustainability aims to give students the knowledge, skills and attributes to address current and future challenges in their personal and professional lives (Sterling, 2001 in Holdsworth & Sandri 2014). Sterling (2001) introduced 'education as sustainability', as 'a transformative, epistemic education paradigm, which is increasingly able to facilitate a transformative learning experience' (p61). In the built environment discipline, education for sustainable development ought to encourage students to understand processes of technological change by thinking carefully and critically of technology design, production and application in the built environment (Kamp, 2006). In a study that aimed to critique the effectiveness of a sustainability course delivered to architecture undergraduate (UG) students it was suggested that students were expected to be able to develop a critically reflexive approach towards their own practice by using the concept of sustainability to explore assumptions, biases and the limitations of existing approaches to practice (Holdsworth & Sandri, 2014).

### ***Sustainability in the Egyptian education and training***

Education is a fundamental tool for capacity-building in all public and private sectors. The United Nations' Sustainable Development Goal targets declared that to achieve many of its targets this will require building skills and experience through specialised education interventions (UNESCO, 2016), for example in water management or addressing global health. Those education interventions ought to have some common short and long term benefits across related sectors, in order to optimise the use of available funding targeted for education. The UNESCO's Global Education Monitoring Report (2016), suggests that collaborative work between different stakeholders; such as the government, civil society, and private sector alongside international actors to fund education for sustainable development in its various facets and levels is needed particularly for low income countries. This would help those countries build their expertise by aligning HE, vocational institutions, and adult learning programmes with the sustainable development targets identified in the United Nations' fourth Sustainable Development Goal; Quality Education (UN-DESA, 2017).



In Egypt, several public and private HE providers established degree programmes that focus on sustainability. In a study concerning trends in Arab architectural education Salama & Amir (2005) found that only two universities in Egypt facilitated Sustainability and Environmental Consciousness related courses at UG levels; Cairo University and Misr International University, in the form of core and optional modules. Subsequently, other HE institutions introduced sustainable and environmental design at PG level while others introduced sustainability as either core or optional modules at UG levels. Of those HEIs that have taken a significant initiative to educate for sustainability in the built environment; Ain Shams University, Cairo University, Arab Academy for Science, Technology and Maritime Transport, the British University in Egypt, and Misr International University are the most acknowledged ones. However, the current provision of UG and PG programmes could not cater for appropriate and timely advancement of ESD in Egypt. Another notable capacity building initiative introduced in 2011 in Egypt was the Education for Sustainable Development beyond the Campus (EduCamp) Tempus project. The project aimed to promote and implement ESD within all education levels in Egypt and developed ESD resource kits for schools and developed a School Teachers' Training Programme to support teachers' classroom activities for SD (EduCamp, 2011). Sewilam et al (2015) suggested a longitudinal study would be essential to assess the impact of the initiative on teachers and trainers who have applied their training to practice.

In the context of construction work, the most commonly used definition of sustainable development is: 'The built environment provides a synthesis of environmental, economic and social issues. It provides shelter for the individual, physical infrastructure for communities and is a significant part of the economy. Its design sets the pattern for resource consumption over its relatively long lifetime' (Prasad & Hall, 2004). Initiatives to address sustainable design and construction of buildings have recently received significant support in Egypt and have been integrated in building codes, and standards. As a result, a public reviewed version of the Green Pyramid Rating System (GPRS) was introduced in 2011. The GPRS is a whole-building approach to sustainability that recognises performance in seven key areas: Sustainable Sites Development, Water Efficiency, Energy Efficiency, Materials and resources, Indoor Environmental Quality, Management, and Innovation and Design Process (Housing and Building National Research Centre (HBRC), 2011).

There has been no definite plan for the release of the final rating system partially; due to the voluntary nature of this initiative besides the lack of training available to produce qualified building assessors. It is expected that the GPRS will require compliance by professionals of all disciplines engaged in the design, procurement, construction, and management of the built environment in Egypt in the near future (Elsharkawy & Zahiri, 2017). Educating and training students, architects, engineers, practitioners and professionals who will employ this rating system in their planning, design and construction and environmental performance assessment of buildings is eminent. However, due to the significant gap which exists in current curricula taught at UG and PG levels and its direct link to market needs that fulfil sustainability demands outlined by Egypt's SDS.

### ***BC-SDBE overview, aim and objectives***

In response to these challenges, the BC-SDBE project was funded in 2016 by the British Council under the Newton Institutional Links fund. Learning from the UK experience in promoting education for sustainability, the project aimed to promote the integration of sustainability in education, training, and practice in the built environment in the Egyptian

context, offering potential educational frameworks that support curriculum development at pre- and post-professional levels. The BC-SDBE project, as a capacity-building initiative, aims to provide learners with a concrete base of knowledge and understanding of the principles of sustainable development, both in theory and practice focusing on critical and reflective application of theory and principles of sustainable development in practice.

The programmes and training established develop the appropriate intellectual and professional skills that supports learners in understanding the feasible tools and techniques in their unique disciplines and help them recognise the accountability of their decisions on the overall sustainability of the built and natural environments, on the macro and micro levels. To enrich the learners' experiences, the programmes engage the multidisciplinary professionals in the field to support and develop self-directed learning, undertaking research, and critical evaluation of available and innovative solutions (Elsharkawy & Zahiri, 2017). Learners are challenged to develop transferable skills through proactive engagement in the learning process and learning by doing. Learners are also supported to confidently disseminate their learning experience and knowledge in their profession through direct interaction with their peers in their communities and in their practice. Effective stakeholder participation in the form of workshops has also promoted a grass roots interest within the built-environment community instead of a top down approach.

This paper aims to present and critically analyse significant outcomes of the BC-SDBE project. The paper will be discussing the results and analysis from the skills-gap survey. It explores the existing barriers to the clear and consistent attention to sustainability in built-environment-related disciplines in Egypt, and discusses challenges faced to effectively integrate sustainability in education and practice.

### **Skills-gap survey results**

The aim of the survey is to reach out to diverse stakeholders within disciplines related to the built environment in order to identify the current skills gaps in sustainable design education, training, and practice. It also aims to determine the required skills and qualifications for effective sustainable design practice within the Egyptian construction sector which in turn will help steer BC-SDBE training programs. The questionnaire is formed of 9 sections with a total of 52 questions. The target audience is UG and PG students, academics and researchers from built environment related courses at Egyptian universities, and practitioners in the construction sector. The questionnaire has been created on Bristol Online Survey tool and distributed via email and social media to a wide audience in Egypt in June and July 2017. Seventy two responses have been collected over a duration of 4 weeks. More than 600 potential respondents started the questionnaire but only 72 completed it. Some respondents commented that the questionnaire was too long, hence the relatively low number of completed responses.

Twenty two per cent of all respondents are students while 78 per cent are graduates (academics and practitioners). Fifty two per cent of respondents are undergraduates or graduates of Ain Shams University, 12 per cent from Cairo University, and 34 per cent from the British University in Egypt, Helwan University, Alexandria University and other universities in Egypt. Seventy per cent of respondents are architectural engineers, while 16 per cent are urban planners, and 11 per cent environmental designers. Eighty one per cent of respondents are graduates of national universities in Egypt which have relatively higher entry requirements compared to private universities. Nineteen per cent are graduates of

private universities in Egypt. Notably, 41 per cent of respondents hold doctorate degrees, while 24 per cent hold masters' degrees and 28 per cent hold Bachelor of Science degrees.

Concerning acquired knowledge in sustainable design practice; 54 per cent of graduate respondents agreed they have not been provided with knowledge in this area during their UG studies, while 38 per cent of graduates who have completed postgraduate studies agreed they have not acquired knowledge in this field during their studies. However, 43 per cent of graduate respondents acquired knowledge in sustainable design practice through individual research in the area of sustainable design, while the same percentage thought they acquired relevant knowledge through hands-on work in practice. Sixty seven per cent attended training sessions and workshops within the field of sustainable design to acquire appropriate knowledge; 44 per cent of those attended recognised / credit-bearing training workshops - 69 per cent of those hold postgraduate degrees.

Sixty three per cent of student respondents agreed that topics related to sustainability are integrated into their curricula. Seventy three per cent of student respondents agreed they would consider environmental design aspects when developing design projects, while 93 per cent would consider functional requirements which was the highest aspect followed by 87 per cent perceived project representation aspect as a main priority. Sixty per cent would consider philosophical / conceptual aspects to design for their design projects. Concerning whether sustainable design is taken into consideration in architectural design studios, 73 per cent of student respondents agreed, while 60 per cent would consider it in urban planning, 80 per cent in urban and landscape design, while 71 per cent would consider it in technical design and installations.

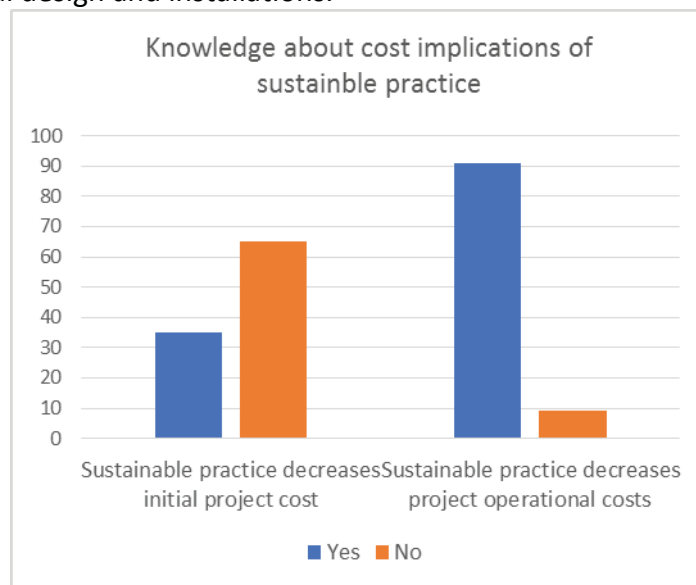


Figure 1: Knowledge about cost implications of sustainable practice

Concerning graduates and professionals in a question about considering several aspects in their design projects; 79 per cent agreed energy performance and energy optimisation are considered in their design projects; 68 per cent of those hold postgraduate degrees, while 49 per cent agreed to water management, 79 per cent indoor environmental quality, 59 per cent agreed to sustainable sites, 70 per cent construction materials, and 51 per cent considered waste management. In response to a question about whether sustainable design in practice decreases the initial cost of projects only 35 per cent agreed, while 91 per cent agreed sustainable design would decrease projects' operational costs.



Sixty nine percent of graduate respondents reported they are involved in teaching, with 47 per cent teaching undergraduates only, 3 per cent teach postgraduates only, while 50 per cent teach both undergraduates and post graduates. Forty five per cent of those involved in teaching have more than 10 years of experience. Sixty per cent of those teaching teach sustainable architecture, 48 per cent teach energy efficiency in buildings while only 30 per cent teach resource management. Eighty five per cent of those involved in teaching agree their institutions encourage students to consider sustainability issues in projects, assignments and other activities. Notably, 80 per cent assert that topics related to sustainability are integrated in their courses with 47 per cent using lectures in teaching and 38 per cent using case studies, while only 29 per cent using self-directed learning (respondents could choose more than 1 method). Only forty per cent of academics who teach postgraduates rely on self-directed learning as a method for teaching. In response to the question about resources that academics rely on to prepare their courses; 48 per cent undertake research, while 32 per cent reply on web materials, and only 21 per cent undertake professional training to acquire the knowledge required for teaching.

Sixty four per cent of academics mentioned they are involved in scientific research related to sustainable design and development. Lack of resources have been highlighted as one of the reasons for the relatively low engagement of academics in research where 68 per cent state this is due to lack of experimental laboratories, 33 per cent lack of specialist softwares, and 55 per cent lack of financial resources that support research. On the other hand, 74 per cent agreed they can refer to case studies from practice to learn from, 68 per cent agree they have a databank for local environmental studies, and 85 per cent consider their academic background helped facilitate their research work.

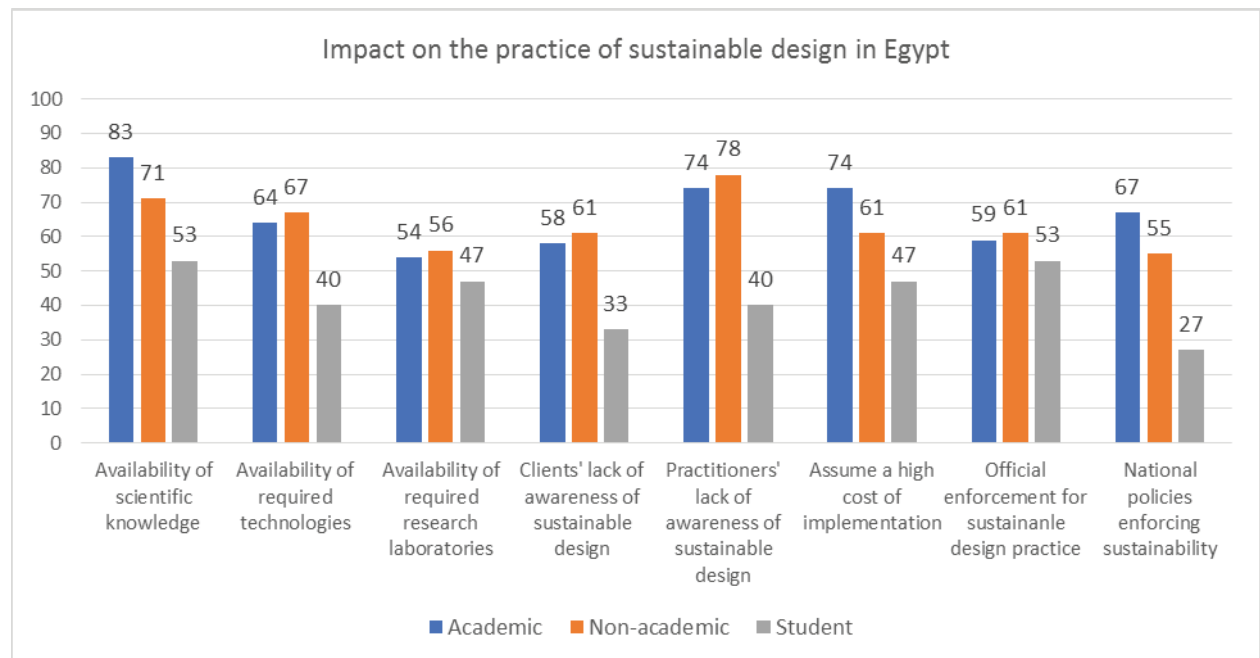


Figure 2: Factors that impact on the practice of sustainable design in Egypt

With regards to aspects which have an impact on the practice of sustainable design in Egypt, 83 per cent of academics agree that scientific knowledge is available, 71 per cent of non-academics/professionals agreed to this statement, while only 53 per cent of student respondents agreed to this statement. Sixty four per cent of academics agreed there available technologies in the local market, 67 per cent of professionals agreed, while only 40

per cent of student responses agreed to this statement. Fifty four per cent of academics agree there are available research laboratories, 56 per cent of non-academics / professionals agreed, while 47 per cent of students agreed to this statement.

Concerning other aspects that cause weak sustainable design practice in Egypt lack of awareness from various stakeholders namely clients / developers and the general public comes as the first recurring factor viewed by graduate and professional respondents. Lack of specialist knowledge from the practitioners' side concerning appropriate strategies and technologies for sustainable design and performance has been reported as another hurdle to mainstreaming sustainable design practice which is by and large due to the lack of specialist knowledge acquired at graduate and professional levels. This lack of awareness from various stakeholders exacerbates the pressure on the country's natural resources; including water, natural gas and oil (Elsakka, 2015).

The second implication mentioned is the lack of financial resources that support the development and implementation of sustainable design and construction both, at individual and national levels. This is further asserted by Elsakka (2015) in which the study focuses on challenges in achieving sustainable urban development in Egypt where the economic factor plays a significant role. There seems to be a presumption that designing and constructing sustainable buildings would significantly increase the initial cost of a project in spite of the estimated payback in operational and maintenance costs.

Another factor that has been highlighted at several responses is the lack of a regulatory framework that enforces sustainability measures in the construction sector. This agrees with Abdel Wahab (2003) who asserted that Egypt does not lack environmental plans, but rather, lags in the use and application of these plans due to the weak regulatory compliance and enforcement. The current environmental policy in Egypt has proven to be unproductive partially due to its failure to identify factors preventing its successful implementation; such as poverty and the need to further develop (McKenna, 2013). In this same study (Abdel Wahab, 2003), it was suggested that in order to achieve sustainable development in Egypt, a close collaboration between environmental experts and decision makers is required. Short and long term plans for achieving sustainable development should be regulated by national law and associated policies (Elsakka, 2015).

One respondent summarised the issues accounted in Egypt: "The initial cost of constructing a sustainable building cannot be underestimated. Since clients do not understand its importance, practitioners do not highlight the idea of sustainability, and with no official enforcement of practicing the notion of sustainable design practice in Egypt may be regarded as a forgotten matter." As for student respondents, their three main factors that delayed the implementation of sustainable design in practice were: lack of awareness, lack of knowledge and experience, and anticipated high initial cost.

Eighty one percent of those who had attended workshops or training in the field of sustainable design agree they consider energy performance and optimisation in design projects, while 87 per cent agreed they considered indoor environmental quality in design projects. By exploring correlations using Spearman's correlation coefficient between those who confirmed their attendance to workshops or training related to sustainable design and priorities taken into consideration in design projects, a positive but weak relation appears with those agreeing that indoor environmental quality is considered in their design projects ( $r = 0.262$ ,  $p < 0.04$ ). Moreover, a strong relation appears with those who agreed they consider sustainable sites in design projects ( $r=0.366^{**}$ ,  $p<0.006$ ). Another positive relation appears with considering appropriate materials and resources ( $r=0.345$ ,  $p<0.01$ ). On the

other hand, a negative and strong relation appears with those who disagreed that high cost of implementing sustainable design technologies is one of the factors that impact on the practice of sustainable design in Egypt ( $r=-0.38^{**}$ ,  $p<0.004$ ).

Notably, a strong and positive relation appears between those who agreed they take energy efficiency and optimisation into consideration in their practice with agreeing that they also consider water management ( $r=0.614^{**}$ ,  $p<0.001$ ), indoor environmental quality ( $r=0.416^{**}$ ,  $p<0.002$ ), sustainable sites ( $r=0.372^{**}$ ,  $p<0.006$ ), materials and resources ( $r=0.376^{**}$ ,  $p<0.005$ ), and waste management ( $r=0.395^{**}$ ,  $p<0.003$ ). There appear several strong and positive relations between those who agreed there is lack of experimental laboratories and resources at universities to support research in sustainable design with those agreeing that there is lack of financial resources to support sustainable design research and practice ( $r=0.552^{**}$ ,  $p<0.001$ ), and the lack of national policies enforcing sustainable design practice ( $r=0.387^{**}$ ,  $p<0.005$ ).

### **Conclusions and recommendations**

BC-SDBE initiative aims to develop a comprehensive and interdisciplinary knowledge base of sustainability principles in theory and its application in practice for Egypt. The training and educational programmes attempt to focus on bespoke mechanisms for sustainable design, and performance of buildings, neighbourhoods, and cities. The first training programme took place in September 2017 where a transformative learning approach has been adopted to implement a balanced and strategic insight into environmental, socio-economic and technical aspects of designing for a sustainable built environment in the Egyptian context. The training methodology proposes a framework for achieving sustainability in the BE supported by proactive participation of stakeholders in the built-environment-related disciplines. This is in the form of stakeholder surveys and focus groups to outline the specific needs and demands in the construction labour market in Egypt.

The survey results provided an insight into current education and practice of sustainable design in Egypt, with a sample of academics, practitioners, and students responding to a variety of questions. The survey aimed to extract the skills gaps in the sustainability education and practice and find the deficiencies in the mechanisms required to support it. Although nearly half the respondents are students / graduates of one university in Egypt, the analysis could still provide a clear picture of the current status particularly that the results could be verified against similar studies and surveys that have taken place internationally. From the findings, it appeared that only 20 per cent of respondents acquired knowledge about sustainable design at UG levels, while 26 per cent acquired this from postgraduate level, and 18 per cent acquired this from individual research and likewise from professional practice. This demonstrates the evident lack of EfS at UG levels where the curricula in the built environment should be based around sustainability as a framework that brings together various elements of the curricula. This also demonstrates the imperative to integrate sustainability in postgraduate practical training and continuous professional development of practitioners.

The survey also indicated there was a widespread impression that the initial cost of sustainable construction projects is generally higher than conventional construction approaches (with 35 per cent agreeing to this). This reflects the lack of knowledge that initial costs of a project would be dependent on the approaches adopted to design for sustainability (starting from planning stages down to construction materials, and energy efficiency measures). However, the majority (91 per cent) agreed sustainable design of

buildings reduces operational costs. Another significant finding concerning reasons for the low engagement of academics in research related to sustainable design was the lack of resources where 68 per cent stated there was a lack of experimental laboratories, 33 per cent lack of specialist softwares, and 55 per cent lack of financial resources that support research. This has been verified in the seventh pillar of the SDS 2030, Education and Training, where some of the challenges have been asserted as the lack of financial resources due to the increasing pressure on government funding as the main source for supporting HEIs, accompanied with accelerating inflation and the devaluation of the Egyptian national currency.

Finally, the majority of respondents agreed the current environmental policies in Egypt are under regulated and inadequately enforced due to the lack of regulatory frameworks that ensure the laws are strictly adhered to. There is also inconsistent reliance on other organisations and NGOs to support sustainable development policies which are heavily influenced by international policies and funding agencies such as the World Bank and the USAID (McKenna, 2013). Hence, achieving sustainable development in Egypt requires a significant paradigm shift throughout the society as well as the engagement of stakeholders from educators, practitioners, developers, NGOs and policy makers. This engagement at a local level needs to be supported by the partnership and engagement of international experts to facilitate a collective action towards the shared goals of sustainable development. Education for Sustainable Development in Egypt could also benefit from an overall strategic framework which positions it at the heart of the education policy agenda, progressively at all levels of education. This would provide necessary coherence, direction and incentive to existing and future initiatives and scale-up and build on existing good practice (UK National Commission for UNESCO, 2013).

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## References

- Abdel Wahab, R. (2003). Sustainable Development and Environmental Impact Assessment in Egypt: Historical Assessment. *The Environmentalist*, 49-70.
- Altomonte. (2012). *EDUCATE Criteria for Professional Qualification*. Nottingham: EDUCATE press.
- Altomonte, S., Rutherford, P., & Wilson, R. (2014). Mapping the way forward: Education for sustainability in architecture and urban design. *Corporate Social Responsibility and Environmental Management*, 143-154.
- Avila, L. V., Filho, W. L., Brandli, L., Macgregor, C. J., Molthan-Hill, P., Gpkcin, O., & Moreira, R. M. (2017). Barriers to innovation and sustainability at universities around the world. *Journal of Cleaner Production*, 164, 1268-1278.
- Barth, M., & Michelsen, G. (2013). Learning for change: an educational contribution to sustainability science. *Sustainability Science*, 8(1), 103-119.
- Central Agency for Public Mobilisation and Statistics (CAPMAS). (2014). *Labour Force Survey, Quarterly Bulletin, First Quarter (Jan-May 2014)*. Cairo: CAPMAS.
- Construction Review. (2015, December 7). *Construction industry in Egypt to grow by 8% in 2016*. Retrieved from Construction Review Online: <https://constructionreviewonline.com/2015/12/construction-industry-in-egypt-to-grow-by-8-in-2016-says-report/>
- Cotton, D., & Winter, J. (2010). 'It's not just bits of paper and lightbulbs': a review of sustainability pedagogies and their potential for use in higher education. In P. Jones, D. Selby, & S. Sterling, *Sustainability Education: Perspectives and Practice across Higher Education*. London: Earthscan.

Dlouha, J., & Pospíšilova, M. (2017). Education for Sustainable Development Goals in public debate: The importance of participatory research in reflecting and supporting the consultation process in developing a vision for Czech education. *Journal of Cleaner Production*, 1-14.

EduCamp, 2011. Education for Sustainable Development beyond the Campus. [Available Online] URL: <http://educamp.lfi.rwth-aachen.de/> [Accessed 13 April 2017].

Elsakka, S. (2015). The challenges confront the developing countries in applying sustainable urban development - an application on Egypt. *Journal of Advances in Social Science Humanities*, 7-13.

Elsharkawy, H., & Zahiri, S. (2017). Education for Sustainable Development of the Built Environment: Problem-Based Learning Approach for Embedding Sustainability. *Proceedings of 33rd Passive and Low Energy Architecture (PLEA) International Conference*. Edinburgh: Network for Comfort and Energy Use in Buildings.

Holdsworth, S., & Sandri, O. (2014). Sustainability education and the built environment: Experiences from the classroom. *Journal for Education in the Built Environment*, 48-68.

Housing and Building National Research Centre (HBRC). (2011). *The Green Pyramid Rating System, First Edition - April 2011, for public review*. Giza: Green Building Council.

Kamp, L. (2006). Engineering education in sustainable development at Delf University of Technology. *Journal of Cleaner Production*, 928-931.

McKenna, M. E. (2013, June). Sustainable Development and Environmental Policy in Egypt. *Master of Arts in International Human Rights Law*. Cairo, Egypt: The American University in Cairo.

MOPMAR. (2016). *Sustainable Development Strategy: Egypt's Vision 2030*. Cairo: Ministry of Planning, Monitoring and Administrative Reform.

Murray, P., & Cotgrave, A. (2007). Sustainability literacy: The future paradigm for construction education? *Structural Survey*, 723-746.

Prasad, D., & Hall, M. (2004). *The Construction Challenge: Sustainability in Developing Countries*. London: RICS.

Salama, A. & Amir, A. 2005. Paradigmatic trends in Arab architectural education: Impacts and challenges. UIA Congress, Istanbul, Turkey, July 2005.

SDS Egypt 2030. (2016, May 17). *Reports*. Retrieved from Sustainable Development Strategy: Egypt Vision 2030: <http://sdsegypt2030.com/wp-content/uploads/2016/08/English-Booklet-2030.compressed.pdf>

Sewilam, H., McCormack, O., Mader, M. & Abdel Raouf, M. 2015. Introducing education for sustainable development into Egyptian Schools. *Environmental Development and Sustainability*, 17, pp. 221-238.

Sterling, S. (2001). *Sustainable Education Re-visioning Learning and Change (Schumacher Briefings no.6)*. Bristol: Green Books.

The People's Movement for Human Rights Education. (n.d.). *The Human Right to Sustainable Development*. Retrieved from The Human Right to Sustainable Development: <http://www.pdhre.org/rights/sustainable-development.html>

UK National Commission for UNESCO. (2013). *Education for Sustainable Development (ESD) in the UK - Current status, best practice and opportunities for the future*. London: UK National Commission for UNESCO.

UN-DESA. (2017). *United Nations Sustainable Development Knowledge Platform*. Retrieved from <https://sustainabledevelopment.un.org/sdg4>

UNESCO. (2016). *Global Education Monitoring Report. Education for People and Planet: Creating Sustainable Futures for All*. Retrieved from UNESCO: <http://unesdoc.unesco.org/images/0024/002457/245752e.pdf>

World Bank. (2014). *CO2 Emissions (kt)*. Retrieved from The World Bank Data: <https://data.worldbank.org/indicator/EN.ATM.CO2E.KT?end=2014&locations=EG&start=1960&view=chart>

# Education with(in) practice: Reducing the gap between architectural practice and education

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**Abstract:** At the Faculty of the Built Environment (FoBE), as with other Architecture or Engineering programmes, students at the end of a particular year are required to find a site on which to undertake Industry Placement. Over the years though, following assessment of student work and observation on subsequent tasks it was evident that students did not necessarily acquire the knowledge, gain the skills nor develop the expected dispositions. This is mainly because not all sites or potential site managers are organised enough, resourced adequately or capacitated to make the student site experience gainful. Studies reveal that an icebreaker is in the extension of learning to involve the practicing architect in strategic ways. In the academic year 2016/17 the FBE pioneered an alternative approach on the Field Experience (Industry Placement) course where three practices embraced the idea of hosting site-based workshops. Preliminary feedback suggests that this approach is a more gainful learning experience. The participation in site meetings, site walks; and later a closer engagement with key members of the project team has proven useful. The expectation to do more research while visiting other sites of one's choice in order to contrast key lessons has given the students an impetus to constantly reflect on their learning as opposed to the passive attitude that was observed in previous years. In addition, peer-to-peer workshops were organised and during these each group was expected to facilitate a session as another way of clarifying key concepts amongst themselves. In terms of architecture detailing and getting to grips with construction, each student was expected to submit iterations of their thoughts in journals and build both CAD and physical models. Students continue to struggle with building construction, reading scales and scaling building construction components. In future, it is planned that more targeted and frequent visits will bridge the gaps overall.

**Keywords:** Practice, Education, Site, Workshops.

## Introduction

The enrolment for industry placement – as it is traditionally referred to – is common across schools offering for example engineering and architecture programmes. While it is a key input to the curriculum in bridging theory and practice, this paper queries its effectiveness today as the principal link between architectural education and practice.

In particular, at the Faculty of the Built Environment (FBE) of Uganda Martyrs University at the end of every second year of the undergraduate programme, students are required to find a site on which to do this. Over the years though, following assessment of student work and observation on subsequent tasks it became evident that students did not necessarily acquire the knowledge, gain the skills nor develop the dispositions as expected. This is mainly because not all sites and not all potential site managers/supervisors are organised enough, resourced nor capacitated to make the student site experience gainful.

In an attempt to reverse this trend, the FBE in 2016/17 experimented a new approach in collaboration with three architecture practices on four projects in which the idea was to host site-based workshops. The primary objectives of and benefits to the three parties are listed below in Figure 1.



Key party	Objective/Benefit
Students	<ul style="list-style-type: none"> <li>• Develop a participatory approach to inquiry into and appreciation of how the design process informs construction and vice versa;</li> <li>• Provide practice with problem interpretation, representation and intervention;</li> <li>• Develop a keenness to process thoughts through sketching, drawing and modeling;</li> <li>• Develop a perceptive outlook of the world as students probe real world issues;</li> <li>• Develop the habits of collaborative and team learning.</li> </ul>
Faculty	<ul style="list-style-type: none"> <li>• Grow our collaboration with practice.</li> </ul>
Collaborating Practice	<ul style="list-style-type: none"> <li>• Contribute to the education of future professionals;</li> <li>• Indirectly engage students as a focus group for feedback on their projects.</li> </ul>

Figure 1. Objectives/benefits to key parties.

## Rationale

In discussing the intentions and outcomes on an experimented approach to industry placement, this paper is offering some insight into how teaching and learning can be enriched in an effort to bridge the gap between architectural practice and education.

Architecture is taught and learned with the design studio as the centre of activity. The design process involves rigorous research, design exploration and an attitude toward implementation informed by precedent and feasibility studies. A keener knowledge of this process is boosted through crits that highlight the expectations of good office practice. This is all grounded in architecture that by default as a built environment (professional) discipline is borne from day to day encounters and needs. However, as has been observed in many schools, construction (architectural practice) is treated as a separate course altogether from design – delivered through lectures, divorced from studio and relying heavily on published material, yet even when taught in an integrated studio it is often conducted as an add-on project on its own (Bouchlaghem, 2006).

Reflecting on the work of Pierre Bourdieu whose writing on socialisation in education sustains the discourse around how and why education is pursued and the role of educators in this pursuit and; the Jungian epistemological balance (Stamps, 1994), where an opportunity to harness the functions of thinking, feeling, sensing, and imagining both individually (introverted) and collectively (extroverted), this paper sets out to reemphasise key considerations for teaching and learning.

Generally, teaching and learning in Higher Education is organized around three themes – Knowledge, Skills and Dispositions. In the context of architectural education the three equivalent themes include the: Intellectual, Technical and Intuitive. These two dimensions are expounded in Biggs and Tang (2011) and Angélil (2003). See Figure 2 below. The process though, ought to be mindful of a reality Shuell (1986) shared that, “what the student does is actually more important in determining what is learned than what the teacher does.”

With reference to Weidman, Twale and Stein (2000) conceptualisation of the socialisation of students on a professional programme, this paper recognises that alongside the studio and the traditional methods of delivery, there are possibilities for more diverse teaching and learning tools and methods.

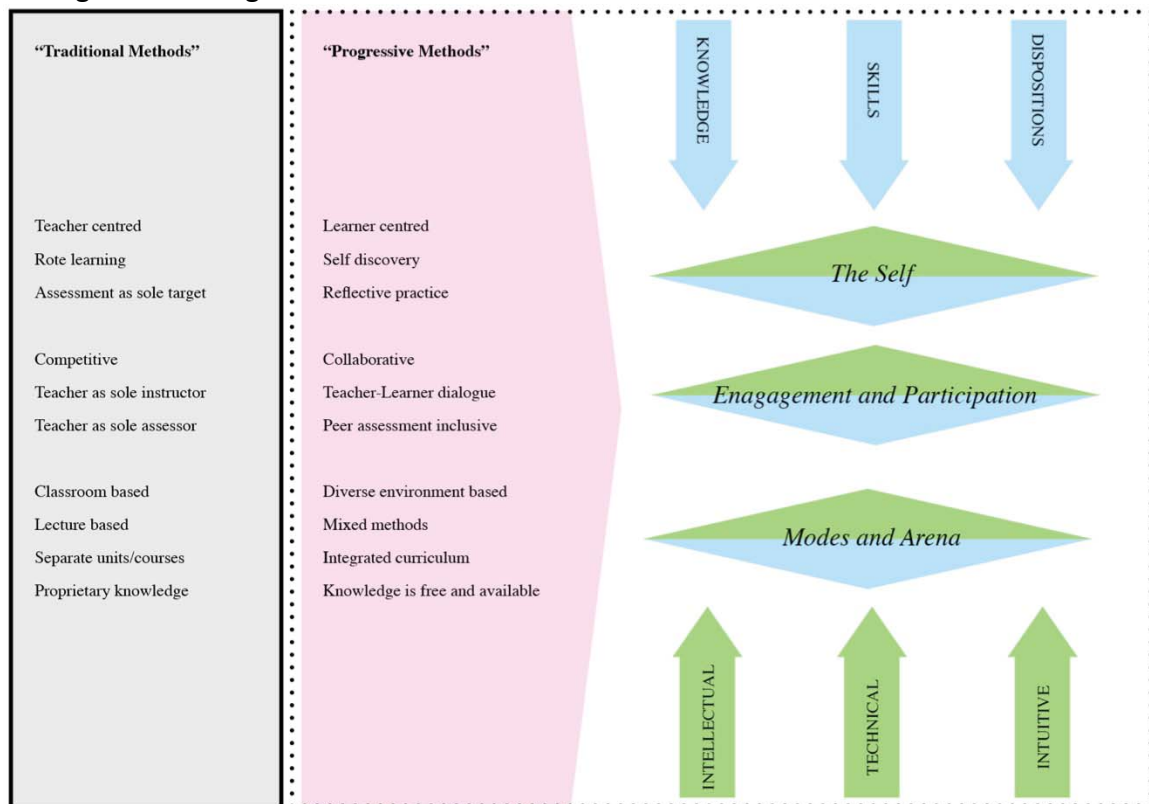


Figure 2: Conceptual framework on broad-based teaching and learning pathways developed further from Biggs and Tang (2011) and Angéilil (2003)

Ultimately, this paper hints upon the opportunity of opening up the discussion between architectural practice, education and later research. While the initial steps are between education and practice, the intended impact is growing a culture in which collaboration between education and practice will reveal the place of architectural research in dealing with the problems of the built environment.

## Context and Objectives

Having changed its name from the Faculty of Building Technology and Architecture, it is now over fifteen years since the Faculty of the Built Environment (FBE) at Uganda Martyrs University was established. The first programmes were the Bachelor of Science Building Design and Technology and the Bachelor of Architecture that were later changed to the Bachelor of Environmental Design and the Master of Architecture (Professional).

*Our multidisciplinary curriculum is designed to foster critical and creative thinking, to enable students and graduates to engage with the environmental, social, and aesthetic challenges of the contemporary milieu. Most courses in the Faculty are taught through a problem-based integrated teaching approach, that integrates design with the techniques and practices of construction, structures, materials and building services, all within a theoretical and historical context, keeping*



*in mind human needs (social, physiological and cultural). (Uganda Martyrs University Faculty of the Built Environment student handbook and outline of courses 2015 - 2016 pp 1)*

The FBE deliberately set out to always be at the forefront of architectural education in the region. The changes were necessary to accommodate an understanding of the profession beyond just a building, as some seem to take it; as such, embracing the wider environment and associated context as part of the complexity of contemporary society. It is nonetheless only prudent to acknowledge that there are several potential directions for architectural education. This is key as the debate regarding how well future practitioners will be prepared to deal with real world problems looms.

Teaching and learning therefore become strategic fora to influence future practice. In a built environment that reveals the gap between education, research and practice and; the weak interrogation of environmental and societal needs, there is need to close the gap through the education process (Dabaieh, Lashin & Elbably, 2017; Dessouky, 2016; Farahat, 2011; Olweny, 2015; Salama, 2009/2010). The objectives of this paper therefore include:

1. To interrogate the context and gaps in industry placement today;
2. To discuss the outcomes of a new approach at the FBE;
3. To develop some strategies that will close the gap between architectural education and practice.

## **Method**

The paper interrogates the context of education with(in) practice, pitting a traditional approach against a pilot attempt with the intention of contributing to harnessing richer teaching and learning encounters. It incorporates students' experiences both individually and amongst peers, contributions from instructors from the faculty and consultants from the collaborating practices and; a review of the work the students were able to do within the objectives of the course. Key points to note:

- Four sites were secured as part of a collaboration with three architecture firms;
- This activity was carried out over June, July and August 2017;
- Site based workshops, coinciding with monthly project team site visits/meetings were held;
- Students were organised into three large groups of between nine (9) and twelve (12) students in order to have well managed workshops on each visit during each month. Each group got one occasion to visit up to two (2) sites in one month;
- Students acted as keen observers during site meetings and inspections;
- Students sought audience of key people after the site meetings and inspections;
- Students independently engaged, observed and documented encounters on site;
- Students in triads facilitated peer-to-peer seminars to be able to engage each other while reflecting on combined encounters.

## **Findings and Discussion**

General feedback from all parties involved suggests that this approach is indeed a gainful learning experience. Interestingly, students who were repeating the course were very thrilled about the experience expressing how much they gained compared to previous sessions. Nonetheless, while students' enthusiasm was evident overall, they also cited some challenges – for example they were not proud of their efforts over the seminars. They

challenged peers on how deep their seminars were; often adding that a lot more should go into preparation in future. Additional comments from the students include:

*The field experience and seminars were a great way to learn and share knowledge. It has been a great experience and opportunity.*

*The seminar was really interesting and engaging. It also proved that seminars are effective in the learning process since you present to your peers and in doing so different opinions/ideas are shared in the process.*

*Failure of the respective groups to use models to communicate their ideas. It would also have been interesting if the different groups had spent more time on site, to me it appears that most groups did more of visiting than participating in the process of construction.*

The participation in site meetings and site inspections (Figure 3) and; later a closer engagement with key members of the project team has proven very useful. This is because whereas in previous years we could not control who the students got to interact with, this time round it was guaranteed that the students would interact with both the consultants and contractors while still on site. In addition, the formal arrangement gave the students a chance to follow up privately in case they needed further clarification.



Figure 3: Engagement on some of the sites.

The expectation to do some more research by identifying published precedents and visiting other local sites of their choice to contrast key lessons gave the students the impetus to constantly reflect on their learning as opposed to the passive attitude that was observed in previous years.

In terms of the appreciation of architecture detailing and getting to grips with construction, each student was required to interrogate what they encountered and submit iterations of reimagined details from each site in the form of sketches in their journals and both CAD and physical models. Following evaluation of student submissions – Figure 4, it was apparent that students continue to struggle with building construction, reading scales and scaling building construction components.



Figure 4: Sample of student submissions – sketching, modelling and documentation.

In addition, peer-to-peer workshops - Figure 5, were organised and during these, each group was expected to facilitate a session as another way of clarifying key concepts amongst themselves. While the students acknowledged these as a useful form of engagement and indeed from an instructor's point of view as well, given the weak appreciation of scale, building details and contract administration the potential of these sessions was not exploited to its full potential.



Figure 5: One of the peer-to-peer seminars.

## Conclusions and Recommendations

*...architectural education is only partly a vocational training (reproducing producers) – despite protestations to the contrary – and that much of its logic derives from the fact that it is also producing consumers of the general culture of the dominant groups in society. (Stevens, 1995)*

This paper provides some insight into the numerous teaching possibilities for educators in Higher Education to have an impactful education process. With reference to Weidman, Twale and Stein (2000) conceptualisation of the socialisation of students on a professional programme, this paper also recognises that alongside the studio and the traditional methods of delivery, there are possibilities for more diverse teaching and learning tools and methods for a rich education experience.

By discussing the intentions, observations and outcomes of one course at the Faculty of the Built Environment of Uganda Martyrs University the paper has revealed that it is possible to purposefully tweak teaching in a deliberate effort to inspire learning. Key in this process is an understanding of the tripartite classification of teaching and learning in: the self; engagement and participation and; modes and arena in as far as they offer a flexible scope within which to define tasks, scenarios and courses.

Students were generally motivated and appreciated this new approach. They were also critical about themselves as far as the seminars were concerned; asserting that they could have organised tasks, presented material and prompted peer-to-peer debate better.

The instructors were generally appreciative of the opportunity offered by the consultants and optimistic about the outcomes generally. The consultants' feedback was mostly positive highlighting issues like keen student interest albeit a weak appreciation of site/construction issues. While the enthusiasm displayed by the students and the commitment from the consultants was admirable, the students did not make the most of this session. Given it was a first, subsequent sessions will benefit from the feedback regarding frequency of visits, length of visits and site orientation sessions early on in the semester leading up to the site visits. In addition, reflecting and acting on feedback from consultants (see below) will also be useful.

*The programme allowed students to witness actual work-in-progress and take part in a site meeting. They were also able to interview the architect and project manager in relation to the various study themes they are working on. Any way of increasing practical awareness during the architecture course seems useful to me, as such I think this is an interesting addition to the curriculum. Having said that, I think it must not replace an obligatory three-months practicum on site (working under a contractor and getting exposed to actual brick and mortar), and another three-months stint in an architectural practice.*

*This is a valuable add to the curriculum and is very necessary to become a well-informed architect. Certainly a longer time period of actual practical experience should be a part of it, but this "introduction" to construction administration is an important part to understanding your role as an architect in the "real world".*

*This arrangement definitely allowed the students to have productive interactions with most of the parties involved in the construction process. I think the meetings were also just short enough that the students were able to retain most of what they observed and the information they got. However, I think it would be immensely helpful if such meetings happened a lot early in the program so that there is observable growth in practical knowledge with each added period of field experience.*

Construction and technology generally remains a challenging area. While specialist instructors elude the faculty (and architectural education in general), it is also a problem of socialisation in architectural education in as far as how it contributes to students' ability to perceive, conceptualise and interpret issues. In future, it is planned that whereas more frequent visits will bridge the gaps overall, specific sessions on building construction/details will be emphasised.

Following earlier work in Argyris and Schön (1974) and more recently in Temple and Bandyopadhyay (2007) this paper has reiterated the role of education and practice in not only working towards increasing professional effectiveness but also kindling the place of architectural research. The ethos of architectural research will begin taking shape when the gap between architectural education and practice is reduced.

A transformational architectural education thus becomes one that engages in alternative pedagogies. It promotes awareness, personal growth and efforts toward change. It engages with research, values and ethics as an inherent part of understanding not only the practice of architecture and building construction but also the human condition. It promotes the radical, pushes the envelope while actively challenging the status quo; it is reflective, critical, and allows students to dream and to solve problems; it learns from the past, to better able to address the challenges of the future, and does not seek to merely replicate the past.



## References

- Angelil, M.M. (2003). *Inchoate: an experiment in architectural education*. Swiss Federal Institute of Technology (ETHZ).
- Argyris, C. and Schön, D.A. (1974). *Theory in Practice: Increasing Professional Effectiveness*. San Francisco: Jossey-Bass Publishers.
- Biggs, J. and Tang, C. (2011). Train-the-trainers: Implementing outcomes-based teaching and learning in Malaysian Higher Education. *Malaysian Journal of Learning and Instruction*, 8, pp.1-19.
- Bouchlaghem, D. (2006). Demystifying Construction: Technology in Architectural Education. *Architectural Engineering and Design Management: Teaching and Learning Building Design and Construction*, 2 (1-2), pp. 5-18
- Boyer, E.L. and Mitgang, L.D. (1996). *Building Community: A New Future for Architecture Education and Practice. A Special Report*. California Princeton.
- Cuff, D. (1991). *Architecture : The story of practice*. Cambridge, MA: MIT Press.
- Dabaieh, M., Lashin, M. and Elbably, A., (2017). Going green in architectural education: An urban living lab experiment for a graduation green design studio in Saint Catherine, Egypt. *Solar Energy*, 144, pp.356-366.
- Dessouky, N., (2016). Architecture and urban education in Egypt: producing designers that are ready to respond to the social and environmental circumstances of the Egyptian context. *Procedia Environmental Sciences*, 34, pp.401-410.
- Farahat, B.I. (2011). Architectural Education Future Experience in Designing a New Curriculum for Undergraduate University Education in Architecture. In *Proceedings of EDULEARN 11 Conference 2011*. Barcelona, pp. 743–757.
- Olweny, M.R.O. (2015). *Investigating the processes of socialisation in architectural education: Through experiences in East Africa*. PhD. Cardiff University
- Olweny, M.R.O. (2010). Investigating the Architecture of Architecture Education in Uganda: Student Perspectives. In *44<sup>th</sup> Annual Conference of the Architectural Science Association ANZAScA – On the edge: Cross-disciplinary & intra-disciplinary connections in architectural science*, ed. by Chris Murphy, Susan J Wake, David Turner, Graeme McConchie and David Rhodes (Auckland, New Zealand: Unitec and The Architectural Science Association ANZAScA)
- Oyaro, E. (2011). Developing Resources for the Training of Architects, *Africa Habitat Review Journal*, 5, pp. 296-302
- Bourdieu P. (1971). Systems of education and systems of thought. *Knowledge and control: New directions for the sociology of education*, pp.189-207.
- Salama, A.M. (2010). Delivering theory courses in architecture: Inquiry based, active, and experiential learning integrated. *Archnet-IJAR, International Journal of Architectural Research*, 4(2-3), pp.278-295.
- Salama, A.M. (2009). *Transformative pedagogy in architecture and urbanism*. Solingen: Umbau-Verlag.
- Shuell, T.J. (1986). Cognitive conceptions of learning. *Review of educational research*, 56(4), pp.411-436.
- Stamps, A.E. (1994). Jungian Epistemological Balance: A Framework for Conceptualizing Architectural Education?. *Journal of Architectural Education*, 48(2), pp.105-112.
- Stevens, G. (1995). Struggle in the studio: A Bourdivin look at architectural pedagogy. *Journal of Architectural Education*, 49(2), pp.105-122.
- Temple, N. and Bandyopadhyay, S. (2007). *Thinking Practice. Reflections on Architecture Research and Building Work*. London: Black Dog Publishing.
- Twale, D., Weidman, J. and Stein, E. (2000). From isolation and competition to sharing and collaborating: Challenging the professional socialization process. In *annual meeting of the University Council for Educational Administration, Albuquerque, NM*.

# Integration Of Sustainable Design Education in to Architectural Design Departments and Implementation Proposals in Studio/Project Courses

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**Abstract:** Sustainability can be described as an inclusive concept which is developed and proposed as an answer for social and environmental problems. Nowadays, while transforming into sustainable culture gains vital importance, field of architecture should not only be evolved in terms of professional practice, but also should be improved and transformed in means of education to include sustainable design criteria. One of the main aspects of this required transformation is the transformation in teaching and learning methods. Problem Based Learning approach is being used in many undergraduate programs of many different fields and is proposed by many researchers to integrate sustainability criteria into curricula. This paper consists using of Problem Based Learning principles within the scope of sustainable design in an architectural design project/studio course. According to findings of this paper, proposal has been put into practice in a studio/project course and the success of proposal was measured by analyzing student projects.

**Keywords:** Architectural design education, Sustainable Design, Problem Based Learning

## Introduction

Sustainability can be defined as an inclusive term which is developed and proposed as a respond to social and environmental problems. In the Brundtland Report (1987) entitled 'Our Common Future' which was written by the World Commission on Environment and Development defined the sustainability 'meeting the needs of the present without compromising the ability of the future generations to meet their own needs'. Its significance in higher education is mentioned at Talloires Declaration which is 'a ten-point action plan for incorporating sustainability and environmental literacy in teaching, research, operations and outreach at colleges and universities'. The aim of this declaration is 'ensuring all university graduates have the awareness and understanding to be ecologically responsible citizens' (ULSF, 1990).

Architects, Planners, Interior designers and designers play a vital role in the creation of the built environment. The significance of design education comes from the role of the designers' in shaping our built environment. For the design students, it is imperative to be aware of how the designers' attitudes, behaviours, actions and decisions can affect our future natural environment and the health of people.

So the design education should respond to this issue with integrating sustainability in to design education. In this case, design education should be improved and transformed in means of sustainable design. Problem based approach is one of the methods to integrate

sustainability in to design education. The aim of this paper is integrating sustainable design in an architectural design project/studio course using the Problem Based Learning principles.

### **Sustainability in Design Education**

The United Nations Decade of Education for Sustainable Development (UN DESD) mentioned the importance of sustainable development with integrating it in all educational settings (Calder et.al., 2005).

In design education sustainability had a lot of conflicts with integrating it to the education and practice. Flynn (2007) claimed it as 'Because the demand for sustainable design is relatively recent and still growing, many people do not have the experience with the processes, methods and ideas that sustainability requires... because of this clients are looking even more to us as design professionals to lead the process'. (Flynn, 2007).

In this context, instructors of architecture started to work on how to educate the architectural designers that sustainability will not be an idea but will be practice. Most of the architectural design schools in Turkey, integrate some theoretical sustainable design courses in their curricula. However as Karslı (2013) mentioned that integrating any theoretical courses are not enough to teach how to apply sustainability in to design.

Design Studio/Project courses are at the core of the architectural design education. Siddigi (2002), describes the activity of learning in the architectural design studio with his own words: 'It is a process, a way of thinking during which the many elements, possibilities and constraints of architectural knowledge are integrated. Design studio sequence provides the connective tissue that brings together, progressively, the many elements of architectural education' (Siddigi, 2002).

Schön (1983) focused on architectural and engineering education in his study called 'Reflective Practitioner' defines the learning activity in the design studio as 'reflection in action'. Bashir et.al., (2013) claimed the combination of Schon's and Woods' (1985) themes as a 'cognitive apprentice' model (also called 'Problem Based Learning'). PBL has been defined in various ways in literature (Albanese & Mitchell, 1993; An, 2006; Arambula-Greenfield, 1996; Barrows & Tamblyn, 1980; Gijbelset al., 2005; Vernon & Blake, 1993). One of the most common definitions of PBL is: "Problem-based learning results from the process of working toward the understanding or resolution of a problem. The problem is encountered first in the learning process and serves as a focus or stimulus for the application of problem solving or reasoning skills as well as for the search for or study of knowledge needed to understand the mechanism responsible for the problem and how it might be resolved" (Barrows & Tamblyn as cited in Hesterberg, 2005, p.4). An (2006) defined PBL as "a learner-centered instructional approach that aims to help learners acquire both domain-specific knowledge and domain independent knowledge, such as problem solving, metacognitive, reasoning, critical thinking, self-directed learning, communication and teamwork skills, by using a problem as the starting point of, and stimulus for, learning in a collaborative learning environment" (p.7).

In the PBL process, it begins with an authentic, ill-structured problem that is presented to a small group of students. The group size is mostly four to seven students. After tutor who is serving as a facilitator presents the problem, students try to determine what they know about the problem and what they need to know to solve the problem. While students collaborate and communicate within the group to define their existing knowledge and knowledge needed to solve the problem, they experience with self-directed learning skills. Students formulate their learning needs as questions. Until the next session, they study



independently and return to the group to discuss, share and synthesize their acquired knowledge. They need social interaction and collaboration skills to solve the problem. Every module/tutorial is concluded with an evaluation part which allows the processes of problem-solving, interaction, and learning. The tutor guides the students by formulating necessary questions. This cycle repeats until a satisfactory solution is achieved (Barrows as cited in LeJeune, 2002; Dahlgren et al., 1998; Nowak, 2001).

In this learning process students are required to analyze problems, before activating the knowledge. With the independent study activities, students are oriented to find answers to their own learning goals (Bashir et.al., 2013). In this method, achieving knowledge is easier to retrieve than knowledge in practical cases (Banarjee & Graaff, 1996).

In the traditional studio learning the evaluation is based on the jury-based review system. This system does not provide the student to develop skills in evaluation of self or peers. Galford et.al., (2015) asserted the reason of the limited use of PBL in architecture schools rely on the assumption of the similarity of the traditional studio learning model and the PBL. However, there are important differences between the two models of design education. While traditional studio learning models are recognized by other disciplines as a useful tool (Kuhn, 2001), PBL can help the students enter the work environment with honed listening skills that reflect society's needs versus design theory (Gutman, 2010).

PBL applies widely to learning in other disciplines and schools. But there has been limited implementation of PBL in to architectural education. Only The University of Newcastle in Australia (Cowdrey, 1994) has been successfully utilizes the PBL for approximately thirty years. (Dutch et.al., 2001). In architectural courses, application of PBL is criticized as to confine to the studio and not to interact with the teaching of other subjects in the curricula (Maitland, 1997). The basic learning elements are the same both for PBL and design studio: self-reflection, interdisciplinary and self-directed learning, ill-defined problems and critical thinking.

In our case study we apply the basic principles of PBL to architectural design studio can be seen in Table 1.

Table 1. Principles of PBL and Proposal for the Architectural Design Studio.

PRINCIPLES OF PBL (Graaff and Kolmos, 2003)	Proposal for Architectural Design Studio
Learning Process, starts with a problem given to the students.	At the beginning 'sustainability' is given to the students but in the framework of general term 'sustainability', they decide their field with studio discussions.
Students make relations with their own experience and the problem	In the design studio students make researches and observations. Case studies are the basic knowledge resources for them.
Learning process consist of decision making, researching and presentation steps.	The design process of students includes research, decision making and presentation stages. In every stage of the design process, discussions have been done with the students. And in these discussions the Tutor has a facilitator role.
Interdisciplinary Learning	Students used knowledge from different fields (such as material knowledge, ergonomics, etc.) through the design process.
Sample Application	We evaluate this item to assess the students projects
Learning with Group	Students carried out the projects in groups.

## Research Methodology

As global warming, changing climatic conditions and the effects of deterioration of ecological balance continue at full speed, in our changing, polluting and consuming world sustainability is a matter to be urgently considered and implemented for all sectors. In this context, one of the most important sectors that cause ecological changes is the construction sector. The issue of sustainability in this sector, which is important for the creation of liveable cities and liveable spaces, has started to be taken into consideration nowadays. Curricula should be renewed in all the technical, social and regional effects of this subject in the trainings to be carried out in the related branches. The effectiveness of the existing courses related to the subject should be increased, the subject should be examined in different forms within the scope of more courses and the training of the prospective candidates should be ensured.

In general, sustainability education should be instilled in pupils from childhood and their sensitivities should be increased. Basic information about recycling in terms of environment, saving and consumption should be added to education curricula and it should be tried to raise children's awareness from primary education. When it comes to vocational training, it is important to be examined with all aspects of the subject and strengthened with applications. In recent years, "sustainability" has been included in the curricula in architectural education. It is aimed to examine the subject in compulsory and elective courses, in different classes and to provide application experience by defining them as a theme in project applications in upper classes. When we look at architectural education curricula in Universities in Turkey, it is seen that the subjects of "sustainability" are generally in the third and fourth grades, and in the second grade projects (housing, guesthouses, etc.) are considered in terms of students' concepts. In the third and fourth grades, sometimes the project concept is based on this concept. In the first grade, it is generally processed in the Introduction to Architecture courses, introduction to the subject with sun, topography, wind directions etc. narratives.

It can be said that there is a similar structure in the Department of Architecture of Mersin University in terms of curricula. In the method that is tried to be implemented in the introduction of architectural design in 2016-2017 education period; Theoretical information given in architecture course is handled in concept context in design course and discussed in critics. In this way, all students are informed about the subject in the criteria's of the projects that adopt this concept.

In the mentioned period, the final project of introduction to architectural design course; designed as "Mersin University Festival Area Design". The design problem is based on the university needs. It was a real design design problem determined by the university administration in order to meet the PBL goal of being a real-world problem generating authentic experiences (Burroughs, Bracato & Franz, 2009). Here, the clients are the university students themselves. In respond to this issues, architectural design students conducted surveys to their peers in university. The surveys show that university students had specific activities that needed to be addressed such as Culture-Art, Design, Sports, Music, Traditional Arts, Science and Technology, Social-Cultural Integration, Fashion, Astronomy, Extreme Sports, Philosophy and Psychology. 8 students have identified at the same time a few themes as concepts such as "Sustainability", "Ecological Life", "Ecological Materials", "Eco-village", "Permaculture", "Organic Agriculture", "Recycling and Fashion Design", "Yoga and Meditation", "Nature and Architecture", "Analogy". This required the architectural design students to research and to think in a interdisciplinary way. At the same

time they also had to consider the environmental and social problems in terms of sustainability. The design problem should respond to integrate the students from different cultures. In the context of sustainability, participatory design is highly relevant for social sustainability (Nieusma, 2004).

The class was divided into four PBL groups due to class size being too large for one PBL. Each group was given a problem statement and had the opportunity to brainstorm ideas before the survey they conducted. The notes from the brainstorming were documented by one of the students. All the notes were taken to the board for all to see in order to work collaboratively. And all the design diagrams and schemes were judged by the client (an outside faculty member) in each of the design evaluation. All the students had to complete a self-evaluation, a peer evaluation and a facilitator (The authors) evaluation. Observations, surveys and document analysis were utilized as data gathering instruments to analyze PBL.

Along with the direction of the clients (outside faculty member) from the conceptual point of view, it is important that the students choose these themes and they are related to the subject in terms of the process. In the given panel critics, the facilitators guided the students about the topics and resources they needed to investigate and how the students would adapt to the information projects they obtained as a result of the researches were questioned and suggested.

In this process, the panel critic which is open to all students has been made known to all first class architectural students with the critics and the basic concepts of sustainability have been studied by students with application support. Students are required to design the university festival area with student clubs, workshops and exhibition areas, accommodation area, performance stage, cafes and restaurants related to themes at 1/500 scale and to solve the settlement plan of this complex by using two different and inclined terrain slopes, to determine the building materials and construction systems they will use, to try to solve the performance areas in a structural sense and to analyze one of the accommodation and catering units in detail at 1/100 scale.

### **Data Analysis**

Four projects are selected as the themes of sustainability and related concepts are mentioned below, and how they are addressed is tried to be explained.

### **Results and Discussions**

#### **First Project (Abdülkadir Sönmez)**

The themes covered in the project are "Permaculture", "Recycling", "Ecological Materials", "Analogy"(Fig.1.). The student, who clarified the festival theme decision on sustainability in the first week and investigated in many ways, used the selected sub-themes in different areas and stages of the project. It has been observed that the student has developed an analogical approach in the process of determining the settlement plan of the university festival area complex.



Fig. 1. Concept of First Project

The student, who formed the settlement diagram with abstracted the branches of a tree, is very successful in relation to the use of slope, relations between the units, open, semi-open, closed spaces. It seems to be important for the use of ecological wood materials in the project. He selected recycled wood materials and adapted them to his project. He especially preferred to use old palettes in the design of the performance scene. The structural structure that he created by bringing it side by side on the roof was used to create a dynamic image by using the back and forth movements behind the stage. He preferred to use ivy instead of using top coverings on the stage and half open spaces and provide shading with planting. The student clubs preferred by the student to be in the field of festival are working on behalf of ecological life and it is planned to make recycling-based design studies at the workshops. There is also a region devoted to the settlement plan for permaculture.(Fig.2.)





Fig. 2. Final View of the First Project

## 2nd Project (İlknur Dağ)

The themes covered in the project are "Ecological Life", "Ecological Materials", "Nature and Architecture", "Yoga and Meditation" (Fig.3.)



Fig. 3. Concept of the Second Project

The student who has anxious to integrate ecological life with modern life aims to relieve the students who have suffered from the stress of modern life and lessons in the festival area designed as integrated with yoga and meditation areas. As most students are, this student has also taken into account the concept that the complex should function in the absence of festivals. She has done research on many topics such as Student Yoga and Meditation philosophy and Japanese Traditional Architecture and has shaped her project in the direction of the directions made by sharing her information with all her friends and project executives during the panel discussion. The scheme of the gridal plan that she succeeded in fitting the sloping land (University Valley) in the project layout is remarkable. Each grid (module) in the complex has been thought individually, sometimes coming together to create a flat space for yoga and meditation, sometimes turning into a pool, sometimes a flower garden. In the selection of materials throughout the project, the use of wood materials is noteworthy. A modern, minimalist architectural style is preferred. Designed as accommodation units, the tree houses were created by adapting the project modules onto the trees. The moving single structure in the project is the stage of performance. It has become a landmark of progeny with its white overlay and folded plaque structure and philosophically. Closed, semi-open, open-field balance is quite good. In the same way, the plant and water elements were applied very well and increased the wealth of the space. It can be said that the level of the learners is very advanced in terms of functions and architectural sense of space. As a result of the design, it was provided to serve the purposes of the project. During the project process, students participated in discussions on ecological life and the adaptation of modern life, shared their ideas and studied the details in detail.



Fig. 4. Final View of the Second Project

### 3rd Project (Öykü Su Özarslan)

The themes covered in the project are "Ecological Life", "Nature and Architecture", "Eco-village", "Organic Agriculture"

The student wants the festival area to be a place of accommodation to be used by lecturers and students outside the festival, and to serve as a living space for 24 hours. The student who chooses the eco-village concept as a concept, examined sample eco-village plans, studies on the ideal village plan. Then she shared it with her friends. In the complex where the accommodation units will be intensive, there will be book cafés, coffee shops and library open 24 hours a day. In addition, the student has taken part of the agricultural areas located in the project wall in the ideal village plans as an organic garden, at the center of the project. It is thought that if a common field organic farming activity is carried out here, the students who want to participate voluntarily in these activities. She thought that the products obtained could be served in restaurants in the complex in the context of "slowfood". Beside garden, there is a performance stage, which is open to amateur groups. During the harvest time, some special activities are planned. The accommodation is planned to be in a quality one or two storey garden. The use of masonry stone was preferred as the construction system.(Fig.5.)



Fig. 5. Final View of the Second Project

### 4th Project (Zahra Bunyadzede)

The themes covered in the project are: "Recycling and Fashion", "Nature and Architecture"

The student, who is between the concept of recycling and fashion, has created a concept by combining these two. While the majority of other projects were attracted to musical performance, this student chose to design a catwalk as a performance stage. As a general scheme throughout the project, there is a tendency-compatible approach that is minimum in intervention to nature. All materials used in the buildings were obtained from recycling.



Because Mersin is a port area, the most dominant building element is the old containers. These are combined with the steel structure to create accommodation units and restaurants. Instead of retaining walls, it is seen that old tires, tree logs, old fabrics are used as top cover material. It is seen that the back walls of the stands are made by filling waste materials (sawdust-stone, etc.) between old woods. Fashion design training is given at the workshops. However, all designed garments are made up of old clothes and materials. Festivals are held at the closing of the workshops at festival times. In addition, the old clothes collected in the student clubs are repaired and reintegrated into the workshops and distributed to the needy owners. The student has also included a social responsibility project in the concept of design.

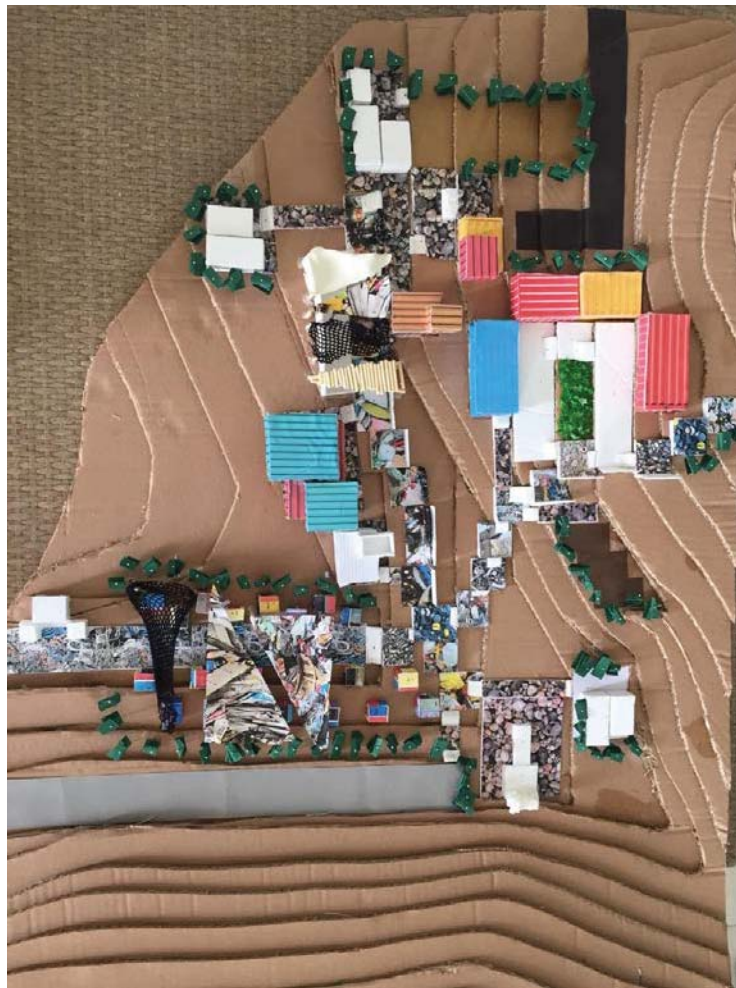


Fig. 6. Final View of the Fourth Project

As a result, it can be said that in all projects ecological life culture, basic concepts of sustainability are discussed, and that students are informed with panel criticisms about the implementation or implementation of these principles. Student 1 preferred to participate in a workshop on mudbrick structures and ecological life in a permaculture farm held by another university during the summer vacation, and this field continued to develop him. In addition, two students who did not work on these themes in the project process, but who were interested in the information with panel critics participated in the same workshop. Together with the information they got from there, they say that they want to specialize in

this subject. It can be said that this training method, which started from the lower classes, has also influenced the students in order to direct their careers.

## Conclusion

The concepts of sustainable design, its relationship to architectural design and its significance have been discussed by authors. In this study the authors used Problem Based Learning approach as a beneficial learning method and can be used for integrating sustainability. Using PBL in the architectural design studio as part of educational background can ease the transition of connection between the academia and the real world problems and quicken the architectural design students' professional maturity. From the students' point of view, Integrating PBL to design studio, also make them to the 'practice-ready' students.

These results are in line with the researches which emphasizes the importance of creativity and the Problem-Based approach (Morris, Childs and Hamilton, 2007) and the researches which investigates the advantages of the problem based approach in educational processes (Kumar and Natarajan, 2007).

This study suggests Architectural Design Studio itself classified as PBL pointed out by Bashir et.al., (2013) and Bridges (1992).

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## References

- Albanese, M. A., & Mitchell, S. (1993). Problem-based learning: A review of literature on its outcomes and implementation issues. *Academic Medicine*, 68, 52-81.
- An, Y. (2006) Collaborative problem-based learning in online environments. Dissertation Abstracts International, 67(06), 106A. (University Microfilms No. AAT3219913). Retrieved, October 05, 2007, from Digital Dissertations database.
- Arambula-Greenfield, T. A. (1996). Implementing problem-based learning in a college Science class. *Journal of College Science Teaching*, 26(1), 26-30.
- Banarjee, H. K. & De Graaff, E. (1996). Problem-based learning in architecture: Problems of integration of technical disciplines. *European Journal of Engineering Education*, 21 (2), 185-195.
- Barrows, H.S. (1994). Practice-based learning: Problem based learning applied to medical education. Springfield, IL: Southern Illinois University School of Medicine.
- Bashir F.M., Ahmad, M.H., Hamid, M. (2013). Design Studio as Problem Based Learning in Architectural Education in Universiti Teknologi Malaysia, The 4<sup>th</sup> International Research Symposium on Problem-Based Learning (IRSPBL). pp. 373-379.
- Bridges, E.M. (1992). Problem based learning for administrators. Eugene: ERIC Clearinghouse on Educational Management.
- Burroughs, S., Brocato, K., & Franz, D. (2009). Problem based and studio based learning: Approaches to promoting reform thinking among teacher candidates. *National Forum of Teacher Education Journal*, 19(3), 1-14.
- Cennamo, K., Brandt, C., Scott, B., McGrath, M., Reimer, Y. & Vernon, M., (2011). Managing the complexity of design problems through studio-based learning. *Interdisciplinary Journal of Problem-Based Learning*, 5(2), 12-36.
- Cowdroy, R. M., & Maitland, B. (1994). Integration, assessment and PBL. *Reflections on PBL*, 45-66.
- Dutch, B.J., Groh, S.E., & Allen, D.E. (2001). The power of problem-based learning. Sterling, VA: Stylus Publishing.

- Flynn, K. (2007). What do clients expect?, *Implications*, 2(9), 4-5.
- Galford, G., Hawkins, S., & Hertweck, M. (2015). Problem-Based Learning as a Model for the Interior Design Classroom: Bridging the Skills Divide Between Academia and Practice. *The Interdisciplinary Journal of Problem-Based Learning*, Vol:9, Issue 2.
- Gijbels, D., Dochy, F., Van den Bossche, P. & Segers, M. (2005). Effects of problem-based learning: a meta analysis from the angle of assessment. *Review of Educational Research*, 75(1) 27-61.
- Graaff, E. De, Kolmos, A. (2013). Characteristics of Problem-Based Learning, *International Journal of Engineering Education*, 19 (5), pp. 657-662.
- Gutman, R. (2010). *Architecture from the outside in*, New York, NY:Princeton Architectural Press.
- Karsli, U.T. (2013). Integrating sustainability in interior design studio, *Procedia- Social and Behavioral Sciences* 106 pp. 1532-1539.
- Kumar, M., Natarajan, U. (2007). A problem-based learning model: showcasing an educational paradigm shift. *Curriculum Journal*, 18(1), 89-102.
- Morris, R., Childes, P., Hamilton, T. (2007). Sustainability by design: a reflection on the suitability of pedagogic practice in design and engineering courses in the teaching of sustainable design. *European Journal of Engineering Education*, 32 (2), 135-142.
- Nieusma, D. (2004). Alternative design scholarship:working toward appropriate design. *Design Issues*, 20(3).
- Siddiqi, A.A. (2002). Architectural design studio projects and the charades of curriculum. The 6<sup>TH</sup> Saudi Engineering Conference, KFUPM, Dhahran, December 2002.
- Vernon, D. T., & Blake, R. L. (1993). Does problem-based learning work? A meta-analysis of evaluative research. *Academic Medicine*, 68(7), 550-563.

# Sustainability and Transformational Education: Reflections on Architectural Education in East Africa

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**Abstract:** Across East Africa, sustainability in architectural education is still viewed with a heavy dose of scepticism, and not been fully embraced as a means to engage with the developmental needs of the region. It is often viewed as a hindrance to development, rather than a means to better engage with the diverse socio-economic factors that are perceived to constrain architecture practice. Sustainability itself is taken as a technoscientific endeavour, unrelated to social-cultural or political issues. This view of sustainability has restricted its uptake, and the growth in knowledge and restricts the implementation of sustainable practices in contemporary architecture, in turn influencing the approach taken by students, who look at the state of practice as a benchmark for engagement with these issues. In rethinking engagement with discourse on sustainability, there is a need to transcend deep rooted socio-political and ideological factors that have determined how sustainability is viewed, and defined its place in architecture and architecture education. As part of a catalyst for transformation in architectural education, and with increasing calls to transform societies and to decolonise education across East Africa, can the sustainability paradigm respond to these transformational challenges? This paper reflects on these issues as part of continuing discourse and research on tropical modernism and educational pedagogy. Through experiences of ongoing developments in architectural education, ideas of sustainability and its place in the architecture curriculum in East Africa are explored.

**Keywords:** Architectural education, Decolonise, Sustainability, Transformational education, Unlearning

## Introduction

Transformation is increasingly taunted as an important shift in education across East Africa, driven by a belief that this could spur development across the region. With reference to architecture, transformational education is of interest as built form, in some way, is a reflection of, and part of discourse that transforms society. Thus, transformational ambitions present as an opportunity to interrogate the intricate link between architectural education and critical discourse, in this case looking specifically at sustainability and Environmentally Conscious Design (ECD). This arises from key concerns related to the need to address pressing social, economic and environmental issues that are an increasing concern for society. To date, however, there has been a prioritising of scientific rationality as the key means to address these challenges as a convenient approach, although not necessarily appropriate (Chee *et al.*, 2011). In the context of East Africa, utterances from architects stating: ‘sustainability is not for us here in Africa’; ‘we do not have any sustainability challenges’; ‘our challenge is a lack of technical know how’ or; ‘we have excess energy in Africa’ would suggest that the status quo approach persists, not necessarily because it is the better approach, neither are these sentiments necessarily correct, but because they are proposed and promoted by people in positions of authority, are perceived to be unquestionable. These could be regarded as constructions based on personal experiences and education, emphasising an unchanging system based in perceptions of the future as “... a conservative extrapolation of the past” (Bermudez, 1999, p. 3). Such statements, made by people in positions of authority, or by senior professionals presents a power relationship that suggests “... the division between the weak and the powerful ...” (Jackson, 1968, p. 10). This serves to restrict engagement with sustainability and ECD, although, and ironically, incidents of electrical blackouts and brownouts, high embodied

energy in building materials, rapid deforestation, etc. suggests an urgent need to engage with these issues within architectural education. This brings forth an intriguing prospect for architectural education: sitting at the crux of this discourse; 'Can this be a catalyst for the transformation of architectural education?' 'Can architectural education take a leadership role in sustainability discourse, to aid its decolonisation through a transformational approach?'

Reflecting on the genesis of these sentiments, framed by the rejection of theories, research and knowledge emanating from the West, and promoted by influential members of postcolonial governments, with rhetoric that reflected post-colonial ideological hegemony which looked to redefine education and post colonial identity. This was achieved through the adoption of socio-political ideologies, with turned universities into instruments for the advancement of political and ideological goals that advanced particular ideals (Kithinji, 2012). As a consequence, anything remotely linked to the colonial era was viewed with healthy scepticism (Myers, 1998), disregarded, or transformed into 'Africanised' versions, in an attempt by post colonial governments to (re)define what it meant to be African in a postcolonial world (Sian, 2007). Ironically, the attempt to dispense with colonial ideologies (at times imagery) served to entrench the status quo, due to a lack of appropriate alternatives, an conflict between institutional desire for a rebirth, juxtaposed with a pent-up desire for modernity. Nevertheless, the emphasis on knowledge as the basis of education was set in place, in a belief that "... knowledge in its pure form [was] considered apolitical and universally relevant ..." (Owolabi, 2007, p. 71). This highlighted the apparent contentions embedded in colonial/tropical modernism, which highlighted the divide between the science and art of architecture, serving to limit development of contextual approaches in subsequent decades. For Smith (1999), the idea of decolonisation should have been based on "... our concerns and world-views and then coming to know and understand theory and research from our own perspectives and for our own purposes" (p. 39). For architecture and architectural education in East Africa, this is a difficult prospect, with the epitome of tropical architecture and the ideal approach to architecture of the tropics intertwined, having been defined in the metropolis, and tied to the threefold classification of the world in relation to England (With regard to British sphere of colonialism): 'Home', 'Sub-Tropics', and 'Tropics'. Despite the architectural mantra initially being taken up in post-colonial nation building, to showcase these modern and forward looking states, initial acceptance of these edifices regarded as apolitical began to fella by the wayside (Chang, 2016). Tropical modernism was discarded as a consequence of its undesirable political links, but with this went many of the innovations embedded in this architectural canon, that had served to critic the tropical condition. Engagement with basic principles of building science and the early beginnings of ECD discourses were sidelined, leaving pertinent issues of sustainable design on the periphery of programmes. With more than four decades passing since this transition, and with renewed interest in the value of ECD in design, there is an opportunity to re-engage with a core value of society, within the transformational agenda, more so as modernism has already radically changed patterns of human settlements and dwellings (Low, 2012). It is thus left for us to address the need for ECD and sustainability in architecture programmes, and to forge a way forward in light of growing calls for increased engagement with sustainability as part of the architecture curriculum, given a study by the African Association of Universities (AAU) identified that this was only evident in less than 10% of built environment programmes (Association of African Universities, 2011).



## Transformational Education

The need for a transformation of architectural education across East Africa, and across sub-Saharan Africa was overtly evident as part of the adjudication of the inaugural African Architectural Awards in 2017, where it was noted by the master jury that a large proportion of shortlisted projects were by architects educated outside the continent (apart from South Africa). This raised questions of the construction of architecture and architectural education across the continent, more so engagement with contemporary challenges on the continent. The contestation emerging from the fast-track to modernity across the region, and largely superimposed from outside the continent, resulted in what Low (2012) described as an unsustainable change in socio-cultural patterns, which have had an impact on perceptions, and engagement with the built environment. This was made more apparent in view of how tropical modernism itself addressed the local, which was little more than a superficial visual endeavour, an approach perpetuated by a lack of architecture schools at the time of independence. In addition, colonial governments had deliberately shied away from developing local knowledge, or fully transferring of knowledge, instead promoting external knowledge as superior. Tropical modernism was thus framed as ‘the’ only valid solution for the tropics, linked to a perception of science as rational and objective. This approach was originally intended to avoid the pitfalls associated with socio-cultural disparities that would otherwise have bogged down development of buildings during the colonial and early post-colonial era. The separation of ‘physiology’ from ‘psychology’ in what Descartes described as “Cartesian Dualism”, was conveniently appropriated by colonial and post-colonial governments, based on the idea that this rational approach was objective, value-free and universal (Loomba, 2005). This apolitical and asocial approach to architecture allowed the propagation of a specific architectural canon despite it having little reference to indigenous communities (Chee *et al.*, 2011), or what Low (2012) presented as ‘cultural genocide’. The apolitical pedigree of tropical modernism was a key reason it was adopted by post-colonial nations: a means to represent the non-homogeneous populations of the newly independent states across East Africa, ignoring the somewhat racist undertones embedded in this canon. Within this setting and with educational content having been passed on unquestioned, incorporating new content such as sustainability and ECD into the architecture curriculum, became a difficult prospect: more than merely adding more content, relabelling courses, or rethinking pedagogy. It requires a reflection on how society and educators perceive the environment, and questioning the science of tropicality that has defined our view of the environment, and the relationship that has formed around this view, as noted by Smith (1999):

Land, for example, was viewed as something to be tamed and brought under control. The landscape, the arrangement of nature, could be altered by ‘man’: swamps could be drained, waterways diverted, inshore areas filled, not simply for physical survival, but for further exploitation of the environment or making it ‘more pleasing’ aesthetically (p. 51).

With this view pervasive across East Africa, a key element of transformational education is to engage in the process of unlearning, to enable change; helping students unlearn, through “... reducing or eliminating pre-existing knowledge or habits that would otherwise represent formidable barriers to new learning” (Newstrom, 1983, p. 36). Unlearning is critical in enabling learning for an unknown future, and for situations of uncertainty, and for which solutions cannot be readily derived from existing approaches.

In seeking to incorporate sustainability into architectural education, a key challenge has been the persistence of a business-as-usual approach, with the status quo, regarded as the only valid approach, maintaining what Burns (2011) described as an unjust cultural system, which in the context of education, serves to perpetuate a hegemonic relationship between educators and learners. The validation of a new architecture programme in one university that sought to incorporate sustainability as a core part of its curriculum for example, found its programme held up simply because it was dissimilar to an existing programme; the evaluation report containing no less than ten references to 'conformity', based largely on comparison with the existing programme, which had changed little in 25 years. This inflexible approach left sustainability on the periphery of programmes, or excluded from curricula altogether, as it did not fit into pre-conceived knowledge systems and pedagogical approaches, or in some cases was simply not part of an instructors' own education. Reviewing contemporary literature on education in relation to East Africa, this conundrum is evident in the publication *New Directions in African Education* (Dlamini, 2008), in which scarce mention is made of 'sustainability', yet a key call throughout the book is for transformative pedagogies geared to changing the construction of education and empower learners. The separation of content from context highlighting some of the challenges in education across East Africa. Transformational learning itself is a process by which "we transform our taken-for-granted frames of reference (meaning perspectives, habits of mind, mind sets) to make them more inclusive, discriminating, open, emotionally capable of change, and reflective ..." (Mezirow, 2000, pp. 7-8). This process is hindered by institutionalised systems that do not favour change, suggesting it would be more effective to implement transformational educational approaches in new institutional contexts rather than by rejigging existing programmes where teaching and learning approaches are already entrenched (Auerbach, 2017, Shay, 2015). Established approaches and associated agenda present education as being little more than a means to an end – a means to gain cultural capital as defined by Bourdieu (1986), and largely to gain employment, but not about personal growth and development of 'self', or 'society' (Foster, 1961, Olweny, 2017). This has translated to finite solutions, in effect building a level of sameness, linked to status, power and privilege, built on an intellectual, ethical, and philosophical struggles between the interests of 'traditional' intellectuals who represent those in positions of authority, and 'organic' intellectuals who represent the changing educational paradigm (Shadar *et al.*, 2011). Engaging with sustainability in this context thus becomes a matter of individual effort, and not a deliberate agenda on the part of an institution. Incorporating sustainability as part of a broader call for transformational education within architectural education may be a means to address some of the persisting challenges of the status quo, and to enable engagement with issues and ideas that can help architecture education transcend the challenges faced in adapting to changed circumstances.

### **Sustainability and the Social [Re]Production of Architecture**

While the technoscientific approach formed a key part of tropical modernism, and was its biggest selling point, this has also been its greatest weakness. Founded on the notion that the climate of the tropics was something to be conquered, leading to the:

... preoccupation with building a comfortable home in the tropics. However, comfort was not just a physical notion linked to natural ventilation and sun-shading; it was also a social, racial and medical notion that depended on spatial



exclusiveness and command over disproportionate economic resources (Chee *et al.*, 2011, pp. 278-279).

The resulting bungalow: with deep verandahs, surrounded by extensive gardens ubiquitous across the tropics, guaranteed comfort for the settler population. This typology was adopted as the epitome of good tropical architecture, regardless of its resource intensity, more so as these were an improvement of the tenement type dwellings provided for local populations that paid little attention to the provision of 'comfort' and which had embedding an 'us-versus-them' diction into the built environment. The exclusion of local populations from the development of tropical modernism, save for the decorative elements on the facades had served to reinforce the social stratification, and with this the idea that 'high' science was not relevant for the general populace, only useful for the elite. It also served to build a perception of education as a means to an end, but not a solution to contextual problems. The socio-political construction of education thus finds its way into engagement with sustainability: defined for and by external experts, and thus perceived as '*someone else's concern*', and not applicable to the local context (Olweny, 2015), and as presented in the utterances presented as part of the introduction. Within education, this has translated into a didactic approach (Parnell, 2003), in a 'do as I say, not as I do' mode, with existing knowledge taken as correct and unchanging, presenting scientific knowledge as irrefutable and not subject to critical interrogation. With teachers wielding immense cultural capital, and significantly influential, more so as they are often the only source of information and knowledge. Thus, "... students who want to pass exams regurgitate[ing] the strong programme, and as science has been given a dominant position in society the public accept a 'strong program' as 'truth'" (Allmendinger, 2002, p. 7). This reflects the challenge of cultural bias, as presented by Smith (1999):

Most of the 'traditional' disciplines are grounded in cultural world views which are either antagonistic to other belief systems or have no methodology for dealing with other knowledge systems. Underpinning all of what is taught at universities is the belief in the concept of science as the all embracing method for gaining an understanding of the world (p. 65).

Although tropical modernism was a product of European colonies in the tropics, the science behind it is largely western, which dismissed indigenous knowledge as insignificant, and somewhat linked to the 'traditional' separation of arts and sciences (See Snow, 1998), which "... enable(d) disciplines to develop independently, their histories kept separate and 'pure'" (Smith, 1999, p. 67). Transposed onto the context of East Africa, this served to distort societal views of the world (Bernstein, 1971), presenting scientific rationality as the only viable means of development, but only through dispelling with local traditions. The principles of tropical modernism, as derived from colonial modernism, included: Consideration for cross ventilation; Orientation to reduce solar gain; Large overhands to block out direct solar gain; Brise soleil to provide protected circulation spines; Large gardens around the buildings, to ensure adequate breezes (and to separate the colonialists from the locals). The epitome of this was the bungalow, ubiquitous across the tropics, and taunted as the quintessential tropical building.

The nature of the bungalow highlights the conflicts embedded in the origins of tropical modernism, and the division between arts and sciences. This generated a degree of resistance and a backlash against a perceived imperialist agenda, exacerbated by post-colonial ideological hegemony, which sought to redefine education across East Africa, most notably evident in education, with "... the three East African governments ... hijack[ing] the

university colleges located in their territories, turning them into instruments to advance their political and ideological goals” (Kithinji, 2012, p. 201). Approaches to education, while still largely based on colonial models, dispensed with social-cultural elements, making use of technoscience as science was perceived to be value free. Within this framework, engagement with sustainability and ECD is fraught with difficulty, as highlighted by Omenya (2011). Nevertheless, this does present an opportunity to engage with sustainability as part of a transformational paradigm for architectural education. Architectural education thus emerges as site of conflict over evolving values, ideologies and power in the quest to define an approach to sustainability in the socio-cultural context of East Africa as part of the broader transformational discourse, acknowledging that science is not value free. The lack of enthusiasm for sustainability and ECD demonstrated a nonchalant attitude toward change, more so in the context of existing administrative frameworks - *‘We have always done it that way’*. This could also be linked to the lack of sustainability in many architecture programmes, with faculty having only limited exposure to sustainability as part of their own education, and thus unable to fully engage with students in this knowledge area (Olweny, 2015). This negates a key role of architectural education: to act as a critic to architectural practice, and as a think tank for the production of architectural knowledge that can advance the profession and discipline of architecture (Till, 1996). It is therefore critical to re-imagine the construction of sustainability in architectural education not as a purely scientific construct, but which is as much a socio-cultural construct as well.

### **Sustainability and Transformational Architectural Education**

Transformational education requires not only new approaches to teaching and learning, but also an ability to interrogate available knowledge in the context in which the information is to be used. For sustainability, this requires engagement with elements that often fall outside the realm of traditional formal education, with ideas often rooted in the ethical and spiritual thoughts of indigenous societies, many needing to be rediscovered (Burns, 2011). A dearth of available contextual information across much of East Africa, along with teaching that discouraged independent thought, have served to limit engagement in sustainability and ECD as drivers for design, or as a goal of design projects. These are often reduced to the stereotypical application of rainwater collection and solar photovoltaics and as add on extras, rather than integrated into the design. The limited engagement with sustainability is often attributed to a lack of available information and good local precedents, resulting in two divergent approaches: use of archaic references as the basis of explorations; or ignoring all references altogether. Both approaches are not particularly appealing in the context of education for an unknown future. The latter does present an opportunity to engage students in innovative evidence-based teaching and learning built around ECD and sustainability. This approach has been fundamental to the growth of design data in landscape architecture education, with students engaged in developing plant databases relevant for design purposes (Cliffin, 2011), and a key approach to innovative and radical approaches to architectural education (See Froud and Harriss, 2015, Nicol and Pilling, 2000). For East Africa, this presents an opportunity to engage students in activities that build links between students’ lived experiences, and the information they are exposed to, something often lacking in the existing education system. Learning-by-doing, also presented as experiential learning by Rodriguez (2017), embedded within it features that could aid the uptake of sustainability and ECD as part of the transformational educational agenda. This plays into the adage by Sir Isaac Newton: “If I have seen further [than others] it is by

standing on the shoulders of giants", suggesting that ideas are scaffolded on engagement with what came before, rather than discarding it in the idea that this knowledge has no place in contemporary architectural education. In this way, it would be possible to bring together the necessary elements that define contemporary architectural education. Experiential learning has at times been problematised, in view of its construction in relatively dynamic educational environments, questioning the discovery-oriented learning, as opposed to direct instruction methods (Chase and Klahr, 2017). In the context of architectural education, looking at the value of architectural education beyond technical competence, and should "... help students develop the ethical grounding, the intellectual roundedness, and the maturity to weigh the impact of their work on present users and future generations" (Boyer and Mitgang, 1996, p. 145). For East Africa, the need for a constructivist approach to education becomes important, so as to engage learners in dynamic knowledge, moving away from the perception of knowledge as static.

Taking ideas from "Task Based Learning" as used in the teaching of foreign languages by Hooper *et al.* (2012), the suggestion of an immersive educational experience was derived, seeking not only to place sustainability at the centre of the curriculum, but significantly, to ground architectural education in place. Explorations would seek to enable students to actively participate in the immersive experiences of producing architecture, or buildings, taking students outside of the lecture room, and into the works of professional architecture and construction and not using the metaphor of a kitchen as was used by Hooper *et al.* (2012). Use of a constructivist approach in contemporary architecture education is a radical transformation of the prevailing educational approach in East Africa, with the prevailing approach not able to readily accommodate divergent points of view, encouraging a degree of sameness in architecture. Constructivism acknowledges that "... there exists multiple, socially constructed realities ungoverned by any natural laws, casual or otherwise" (Guba and Lincoln, 1989, p. 84). In the context of transformational learning, constructivism acknowledges that:

Traditional scientific method, has always been, at the very best, 20-20 hindsight. It's good for seeing where you've been. It's good for testing the truth of think you know, but it can't tell you where you ought to go, unless where you ought to go is a continuation of where you were going in the past. Creativity, originality, inventiveness, intuition, imagination - 'unstuckness' in other words - are completely outside its domain (Pirsig, 1999, p. 286).

A constructivist approach would be an opportunity to encourage transformational learning and engage with Sustainability and ECD, and to begin to effect a shift in the paradigm of thinking, as highlighted by Kuhn (1996). It is here that transformational education and sustainability converge, bridging the gap between students' lived experiences, and the educated world of the future, seeking to recompile it into a holistic norm away from the existence as parallel entities (See Foster, 1961, Pido, 2002). A key tenant of this approach relates to the meaning ascribed to architecture, which links to the philosophical view that are the basis of many architectural endeavours: being, dwelling and glorification (Heidegger, 1971, Pallasmaa, 2011).

### **Transformational Learning and Sustainability in an Undergraduate Programme**

Seeking to rethinking the Part I programme at the Uganda Martyrs University, a key goal was not only to enable students to engage in the broader discourse of architecture; more specifically to take on board elements of sustainability and ECD as core components of the

design of built environments. At the core of this change, was a need to engage with transformational learning as a core element in the new Bachelor of Environmental Design programme. A key part of the move toward engaging with transformational learning was a new pedagogical approach, based around integrated teaching and learning, which was geared to enable a better appreciation of the different components of architecture. This involved re-imagining design courses as integrated entities that incorporated a variety of elements as part of the design process; being conversant of the level of student development, as well as the learning goals and possible outputs. This integrated approach began as part of the first year, which for sustainability and ECD was seen in two courses; *Natural and Built Environment Systems*, and *Culture, Climate and Settlements*. These courses linked design and building endeavours to the historic and contextual conditions, to give both historical and contemporary perspectives on environmental conditions and the built environment. Those courses provided a valuable background for the first building design studio in second year, *Buildings and the Environment*, deliberately framed as a bridge between the outdoors and the indoors, to enable an exploration of the social, cultural and environmental construction of built environments, and the main focus of discussions in this paper. Engagement with integrated teaching and learning continued into the final year of the programme with a more ambitious project that took in broader urban and regional issues as part of design explorations in the course *Sustainable Built Environments*. These courses engaged students in 'non-traditional' learning explorations, specifically seeking to link students' lived experiences to architectural design explorations, an element often missing in architectural education in East Africa. As part of this exploration, engagement with sustainability and ECD emerged from activities that took place around formal instruction.

As part of the effort to link lived experiences with learning, a key part of the course *Buildings and the Environment* involved students documenting their day-to-day activities. This was both in their home settings, as well as in their halls of residence. Documentation included: use of water, electricity, type of fuel for cooking, use of air-conditioners or fans etc. Students were also to seek information on the cost of the various fuels used in their homes, and the quantities used. It was also necessary for students to document their homes in order to enable comparative studies and to build an appreciation between building construction, building size and user experiences. This documentation through measured drawing exercised was to garner information on window sizes and orientation, materials of construction and information on the surrounding environment. Information gathered provided a basis for interrogation of household resource consumption and the link to environmental design issues. It was through this engagement that many students came to appreciate the concept of sustainability, which is for many an abstract notion that is contradictory to the aspirations of a developing nation. Through this engagement, it was thus easier to engage with ECD, built on an appreciation of how design decisions are influenced by (and can influence) engagement with the built environment and thus resource consumption. A valuable part of this educational approach has been the ability to derive environmental design research projects, crucial in generating local knowledge and content that can feed back into the programme.

Linked to exploration of resource consumption, was a need to engage students in collaborative endeavours, regarded as a key feature of transformational education in the context of East Africa given pre-university education has tended to focus attention on competition and individual success, to the detriment of teamwork and collaboration. A

challenge of the status quo approach has been the promotion of a 'do as I say, not as I do' approach, which when coupled with a paternalistic approach to decision making, deters individuals from making decisions, believing that their role is merely to replicate the dominant programme. Live projects, team and group work form close to 50% of the course engagement geared to enable students to question inherent ideas of learning by questioning "... established ideas about who can be learnt from, and what constitutes an expert'" (Chivers, 2015, p. 78). Further, architecture as a profession is largely a collaborative endeavour, not the 'Solo Virtuoso Designer' (Weisman, 1996), the 'Individualistic Prima Donnas' (Howieson, 2000), or the 'Lone Ranger Master Architect' (Briggs, 1996) they are often portrayed as. This is particularly the case for engagement with sustainability and ECD, given the experiences and expertise needed for engagement requires the skills of individuals, many not part of the traditional process of architectural design. This makes engagement with peers, and external stakeholders an important part of transformational learning in architecture, building an understanding of peers and instructors as co-creators and co-investigators as part of a community of learners in the quest for a sustainable future.

While the outcomes overall have been positive, there is certainly scope for further evolution of this educational endeavour. For many students, this is the first time they are actively engaged in critical discourse, and engaged in a high level of formative assessment as part of the educational process, having been used to predominance of summative assessment in their early years of education. This reality has been a challenge in the transition towards an increase in peer to peer learning and group work. Although critical for the development of self directed learning for students transitioning into the Part II programme, there is still a way to go to fully optimise this within the Part I programme. It has also been difficult to fully address perceptions of technoscience as provide correct solutions, more so with government policy prioritising physical science, to the detriment of social sciences, and approach which has served to entrench scientific rationality rather than questioning its embedded assumptions.

## **Conclusion and Reflections**

Engaging with the process of transformational education as part of the new Part I architectural curriculum at the Uganda Martyrs University has been an intriguing process, which was not as straightforward as had initially been envisioned. The process itself was often bogged down due to historical notions of what constituted education, and architectural education, as well as attitudes toward sustainability and ECD. The overall goal had been to ensure the new generation of architects were better prepared to engage with the unknown and unpredictable future, more so with regard to climate change and its impact on future built environments. The post-colonial refocussing of education on ideological grounds had created a void in explorations of climate responsive design, that had left a void in the educational realm. Through transformational education, with an integrated focus on sustainability and ECD, the programme at the Uganda Martyrs University seeks to re-engage with the ideas of climate responsive design, not through replicating the ideas of tropical modernism, but rather through using these early explorations as a historical marker on which to engage with discourse that links to the socio-cultural ideas of place. This approach also serves to enable an appreciation of the construction of knowledge, through learning-by-doing, building links between theoretical content and the social-cultural and political construction of architecture in relation to sustainability and ECD. To goal here being to build acceptance of sustainability and ECD as valuable components of architectural



education but avoiding the politicised view tied to tropical modernism built around the rhetoric of post-colonialism.

The educational approach adopted in this case takes on what has been termed 'flipping the classroom' (Rodriguez, 2017), allowing students to learn in new and innovative ways, engaging with 'lived experiences' (Sara, 2011), and 'experiential learning'. This approach enables the interrogation of idea of environmental design as a theoretical concept, along with its manifestation in the built environment, in this case, in the context of East Africa. Deviating from the traditional educational approach, in which they were largely passive recipients of knowledge, to one in which they actively participate in their learning, The outputs of this endeavour, while rather mixed, do suggest that this approach to architectural education may transcend the perennial argument that the architectural curriculum is overloaded, with no possibility of including new content, and could be an approach to engage not only with sustainability and ECD content, but a broader range of contemporary issues as well. Admittedly, this pedagogical approach is time-consuming to administer, and requires significant patience and flexibility on the part of instructors, who need to be aware of the diverse goals of architecture education beyond the mere design of buildings, and be able to accept that this process can at times produce unpredictable outcomes, although this is a key part of any learning engagement, and important in deviating from prescribed approaches. Regardless of the challenges faced, the revised Bachelor of Environmental Design programme does providing one approach for the incorporation of sustainability and ECD into architectural education; in this case tackling not only the how knowledge is delivered, but also to addressing contextual realities as well. For architectural education in the context of much needed transformation, could this be a catalyst for a new approach to engaging with sustainability and ECD, and a revised view of the value of the science behind tropical modernism, but with relation to the local. More significantly, could this aid in the decolonisation of knowledge within architectural education? Answers to these questions are yet to fully emerge, but engagements as presented in this paper serve as a means to reflect on the process and the emerging outcomes as and when they emerge.

## References

- Allmendinger, P. (2002), *Planning theory*, Palgrave, New York.
- Association of African Universities (2011), "The Promotion of Sustainable Development by Higher Education Institutions in Sub-Saharan Africa: Survey Report", Global University Network for Innovation ((GUNI), International Association of Universities (IAU), Association of African Universities (AAU), Accra.
- Auerbach, J. (2017), "What a new university in Africa is doing to decolonise social sciences", available at: <http://theconversation.com/what-a-new-university-in-africa-is-doing-to-decolonise-social-sciences-77181> (accessed 9 September 2017).
- Bermudez, J. (1999), "The future of architecture education", *87th Association of Collegiate Schools of Architecture (ACSA) Annual Meeting*, Minneapolis, MN., ACSA Press pp. 321-325.
- Bernstein, B. (1971), "On the classification and framing of educational knowledge", in Young, M. F. D. (Ed.) *Knowledge and control: New directions for the sociology of education*, Collier-Macmillan Publishers, London, pp. 47-69.
- Bourdieu, P. (1986), "The forms of capital", in Richardson, J. G. (Ed.) *Handbook of theory and research for the sociology of education*, Greenwood Publishing, New York, pp. 241-258.
- Boyer, E. L. and Mitgang, L. D. (1996), *Building Community: A New Future for Architectural Education and Practice*, The Carnegie Foundation for the Advancement of Teaching, Princeton, New Jersey.
- Briggs, D. C. (1996), "Opinion: Reform the design studio", *Architecture*, Vol. August, pp. 75,77.
- Burns, H. (2011), "Teaching for transformation: (Re)Designing sustainability courses based on ecological principles", *Journal of Sustainability Education*, Vol. 2.

- Chang, J.-H. (2016), *A genealogy of tropical architecture: Colonial networks, nature and technoscience*, Routledge, London.
- Chase, C. C. and Klahr, D. (2017), "Invention Versus Direct Instruction: For Some Content, It's a Tie", *Journal of Science Education and Technology*, Vol. 26 No. 6, pp. 582-596. doi: 10.1007/s10956-017-9700-6
- Chee, L., Chang, J.-H. and Wong, B. C. T. (2011), "Introduction – 'Tropicality-in-motion': Situating tropical architecture", *Singapore Journal of Tropical Geography*, Vol. 32, pp. 277-282. doi: 10.1111/j.1467-9493.2011.00433.x
- Chivers, H. (2015), "Practice makes perfect", in Froud, D. and Harriss, H. (Eds.) *Radical Pedagogies: Architectural Education and the British Tradition*, RIBA Publishing, London, pp. 75-79.
- Cliffin, P. F. (2011), "Online plant databases for design", *EDULEARN 2011, 3rd Annual International Conference on Education and New Learning Technologies*, Barcelona, Spain, pp. 1491-1500.
- Dlamini, S. N. (Ed.) (2008), *New Directions in African Education: Challenges and Possibilities*, University of Calgary Press, Calgary.
- Foster, P. (1961), *White to move? A portrait of East Africa today*, Eyre and Spottiswoode, London.
- Froud, D. and Harriss, H. (Eds.) (2015), *Radical Pedagogies: Architectural Education and the British Tradition*, RIBA Publishing, London.
- Guba, E. G. and Lincoln, Y. S. (1989), *Fourth generation evaluation*, Sage Publications, London.
- Heidegger, M. (1971), *Poetry, Language, Thought*, Harper and Row, London.
- Hooper, C. J., Preston, A., Balaam, M., Seedhouse, P., Jackson, D., Pham, C., Ladha, C., Ladha, K., Plötz, T. and Olivier, P. (2012), "The French kitchen: Task-based learning in an instrumented kitchen", *Proceedings of the ACM Conference on Ubiquitous Computing*, Pittsburgh, PA., pp. 193-202.
- Howieson, S. (2000), "Integrated architectural design: Issues and models", in Nicol, D. and Pilling, S. (Eds.) *Changing architectural education: Towards a new professionalism*, E & F N Spon, London, pp. 155-154.
- Jackson, P. W. (1968), *Life in classrooms*, Holt, Rinehart and Winston, New York.
- Kithinji, M. M. (2012), "An imperial enterprise: The making and breaking of the University of East Africa, 1949-1969", *Canadian journal of African studies/La revue Canadienne des Études Africaines*, Vol. 46 No. 2, pp. 195-214.
- Kuhn, T. (1996), *Structure of Scientific Revolutions*, University of Chicago Press, Chicago.
- Loomba, A. (2005), *Colonialism / Postcolonialism*, Routledge, London.
- Low, I. (2012), "Situated Modernism: The Production of Locality in Africa", in Lim, W. S. W. and Chang, J.-H. (Eds.) *Non West Modernist Past: On Architecture & Modernities*, World Scientific Publishing, Singapore, pp. 127-141.
- Mezirow, J. (2000), *Learning as transformation: Critical perspectives on a theory in progress*, Jossey-Bass, San Francisco.
- Myers, G. A. (1998), "Intellectual of empire: Eric Dutton and hegemony in British Africa", *Annals of the Association of American Geographers*, Vol. 88 No. 1, pp. 1-27.
- Newstrom, J. W. (1983), "The management of unlearning: Exploding the "clean slate" fallacy", *Training and Development Journal*, Vol. 37 No. 8, pp. 36-39.
- Nicol, D. and Pilling, S. (Eds.) (2000), *Changing architectural education: Towards a new professionalism*, E & FN Spon, London.
- Olweny, M. R. O. (2015), "Investigating the Processes of Socialisation in Architectural Education; Through Experiences in East Africa", *Welsh School of Architecture*, Cardiff, Cardiff University.
- Olweny, M. R. O. (2017), "Students' motivation for architecture education in Uganda", *Frontiers of Architectural Research*, Vol. 6 No. 3, pp. 308-317. doi: 10.1016/j.foar.2017.06.002
- Omenya, A. (2011), "Effects of globalization in training architectural design: A case for a pedagogical shift in African schools of architecture", *Africa habitat review journal*, Vol. 5 No. 5, pp. 286-294.
- Owolabi, K. A. (2007), "Knowledge production, cultural identity and globalization: African universities and the challenges of authenticity and transformation in the twenty-first century", in Kenny, J. (Ed.) *The idea of an African university: The Nigerian experience*, The Council for Research in Values and Philosophy.
- Pallasmaa, J. (2011), *The Embodied Image: Imagination and Imagery in Architecture*, John Wiley and Sons, Chichester, West Sussex.
- Parnell, R. (2003), "Knowledge, skills and arrogance: Educating for collaborative practice", in Harder, E. (Ed.) *Writings in architectural education*, European Association for Architectural Education (EAAE), Copenhagen.
- Pido, J. P. O. (2002), "Mismatch in design education at the University of Nairobi", in Miettinen, S. (Ed.) *Art - Design - Education - Exchange with Africa Seminar*, Helsinki, Department of Art Education, University of Art and Design pp. 20-29.



- Pirsig, R. M. (1999), *Zen and the art of motorcycle maintenance*, Harper Collins, New York.
- Rodriguez, C. M. (2017), "A method for experiential learning and significant learning in architectural education via live projects", *Arts and Humanities in Higher Education*, Vol. 30 May. doi: 10.1177/1474022217711878
- Sara, R. (2011), "Learning from life: Exploring the potential of live projects in higher education", *Journal for Education in the Built Environment*, Vol. 6 No. 2, pp. 8-25. doi: 10.11120/jebe.2011.06020008
- Shadar, H., Orr, Z. and Maizel, Y. (2011), "Contested homes: Professionalism, hegemony, and architecture in times of change", *Space and Culture*, Vol. 14 No. 3, pp. 269–290. doi: 10.1177/1206331211412239
- Shay, S. (2015), "Decolonise more than just curriculum content – change the structure, too", available at: <http://theconversation.com/decolonise-more-than-just-curriculum-content-change-the-structure-too-44480> (accessed 9 September 2017).
- Sian, S. (2007), "Reversing exclusion: The Africanisation of accountancy in Kenya, 1963–1970", *Critical Perspectives on Accounting*, Vol. 18 No. 7, pp. 831–872. doi: 10.1016/j.cpa.2006.05.005
- Smith, L. T. (1999), *Decolonizing methodologies: Research and indigenous peoples*, Zed Books, London.
- Snow, C. P. (1998), *The two cultures*, Cambridge University Press, Cambridge.
- Till, J. (1996), "Contingent theory: The educator as ironist", *Stoa No.1* EAAE Publications, Brussels, pp. 66-79.
- Weisman, L. K. (1996), "Diversity by design: Feminist reflections on the future of architectural education and practice", in Agrest, D., Conway, P. and Weisman, L. K. (Eds.) *The sex of architecture*, Harry N. Abrams, New York, pp. 273-286.

# Vernacular Neighbourhoods as Models for Socially-Sustainable Vertical Cities: A Computational Approach

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**Abstract:** The Middle East and North Africa (MENA) region has one of the world's most rapidly expanding urban population. This issue has dramatic impacts on the built environment and increases the need for constructing sustainable vertical buildings. However, most recent developments in the study area have focused on utilising technology and have ignored the potential of incorporating social needs and cultural values. Information gained from a post-occupancy evaluation for contemporary apartment buildings in MENA region show that there are several problems affected the social life of residents. These include lower levels of social support, lower sense of community and familiarity with neighbours, and impacts on children as parents keep them inside apartments due to safety concerns and difficulties of supervision at a distance. Moreover, the excessive use of glazed facades and the standarization of floors destructed the privacy of the family and the identity of each unit. In contrast, vernacular neighbourhoods in the study area represent a successful example of a socially cohesive and healthy environment. For instance, the hierarchical configuration of public spaces and private courtyards allow for a high degree of social interaction between families, and at the same time maintain their privacy. This research aims to benefit from potentials of such horizontal clusters for generating socially-sustainable tall residential buildings that trace the cultural values of the society. Spatial analysis of various traditional neighbourhoods was adopted as a rigorous method for understanding the layout complexity and discovering logical topologies that have social or experiential significance. Using principles of shape grammar, results extracted from the analytical process, associated with specific requirements for vertical buildings, were used to identify sets of parametric rules that combine geometrical properties of spaces with aspects that enhance the social life of residents. Samples of potentially sustainable social solutions, generated by a computational tool, are presented.

**Keywords:** Tall Residential Buildings, Social Sustainability, Courtyards, Spatial Reasoning, Parametric Grammars

## Introduction

The Middle East and North Africa (MENA) region, which is currently home to 357 million people, has one of the world's most rapidly expanding population, with more than 60% (215 million) of urban inhabitants (Serageldin et al., 2015). This number, which is expected to reach the double by 2050, increases the demand for affordable high-rise living and working spaces (Hudgins, 2009; Yeang, 2012; Modi, 2014). A high-rise building is a massive built up spaces on a small footprint. Ken Yeang (2012) claims that this huge volume could be defined as a '*vertical city*', which requires architects to take into account the different pillars of sustainability during the design process to improve the quality of life and to achieve the needs of users. However, the broad attention of sustainable developments is concerned with environmental and economic dimensions rather than the social aspect (Cuthill, 2010). For instance, designs of contemporary high-rise buildings do not reflect a realisation of social spaces, local traditions or appropriate living patterns as a high priority.

A study, conducted by Professor Ade Kearns (2012) and his colleagues (2012) in Glasgow, examines the social outputs of living in high-rise buildings compared to other types of dwellings. They concluded that the current designs of such developments have negative impacts on residents. These issues could be summarised in six categories: (1) fear and insecurity; (2) lower sense of community and familiarity with neighbours; (3) lower

levels of social support due to isolation; (4) lack of identity for each unit due to the standardization of floor plates; (5) mental/physical health effects due to the overcrowded spaces; and (6) impacts on families and children as parents keep their children indoors due to safety concerns and difficulties of supervision at a distance.

In contrast to the contemporary model of vertical buildings, vernacular neighbourhoods in many cities in MENA region (e.g., Cairo, Tunis, Aleppo, Medina, Algeria, Fez, and Marrakech) could be considered as a homogeneous fabric and a socially sustainable townscape (Bianca, 2000; Al-Masri, 2010). For instance, public squares, which have been designed by residents themselves as a response to their needs, norms, behavioural and cultural values, allow for a high degree of social interaction between people, and reflect their sense of community (Al-Jokhadar and Jabi, 2016). Moreover, the hierarchal movement pattern increases degrees of privacy, and at the same time maintains a balance between isolation and interaction (Crouch and Johnson, 2001).

Learning from previous experiences is a suitable way to design with sensitivity as it provides continuity to the existing context, and the cultural roots of the society (Ragette 2003). This research builds on the benefits of the vernacular model of residential quarters to generate vertical developments that could enhance the social life inside these buildings and the well-being qualities, such as privacy and security, for residents.

### **Social Sustainability**

Social sustainability is about reflecting the identity of the place, and the different needs of users, on the spatial design of the physical environment (Berkeley-Group and UK-GBC, 2012). Schwarz and Krabbendam (2013) identified four qualities for socially sustainable designs: (1) sharing and interaction; (2) reflecting local culture; (3) connecting people and their living environment with nature; and (4) focusing on proportion and human scale/comfort.

One of the most difficult issues for designers is how to address these qualities in the design of spatial layouts. Each social quality has different indicators and measurements that could be translated into design specifications (Modi, 2014; Oldfield, 2012; Dempsey *et al.*, 2011; Cuthill, 2010). For instance, the social interaction could be enhanced through the provision of gathering spaces and courtyards inside the building. These common areas are also important features for providing secure playgrounds for children. Reflection of a local culture could be achieved through maintaining the visual privacy of families from neighbours. Therefore, it is recommended to arrange the layout of each floor in a hierarchal system of movement from the public (such as common gathering areas) to semi-private (such as corridors) to private areas (such as apartments). Moreover, entrances of residential units should be arranged in a staggered pattern. Finally, human comfort could be achieved with the availability of green areas, a suitable number of apartments on each floor, and appropriate width of corridors based on the number of people live on the floor.

### **Observations from the Current High-rise Residential Buildings in MENA Region**

Exploring the current situation of residential buildings in MENA region, and recording the different needs of users are important issues for designing a socially sustainable development. A phenomenological survey has been conducted by the authors in the summer of 2016 to develop a holistic picture of the everyday life of residents. The study included a questionnaire distributed to 211 families from 17 countries within the study area. It focused on five aspects: (1) information about the house and the household structure; (2)

spatial descriptions; (3) social merits; (4) environmental qualities; and (5) information about neighbours and the housing context.

Outcomes from the field survey showed that residents expressed their concerns regarding five aspects, which have impacts on the social quality of spaces: (1) security; (2) social interaction; (3) crowding; (4) visual privacy; and (5) accessibility and hierarchy of spaces (see Table 1). Results showed that 71% of the sample who live in apartment buildings considered that their current houses do not afford secure outdoor spaces for children. Furthermore, results indicated that residents have a problem with social interaction with neighbours, as spaces in front of their apartments are limited to narrow circulation paths. To adapt to this social problem, 86% of residents chat with other neighbours at the entrance of the building, and approximately 45% of residents meet and talk with their neighbours at the entrance of their apartment. On the other hand, only 12% and 13% of residents chat with others at the outside garden or the courtyard inside their building respectively. Regarding other social problems in the study area, 62% of respondents reported that they live in houses that have crowded living areas. Moreover, entrances in most current buildings are located directly opposite to each other, which destruct the privacy of the family members. As a suggestion, 87% of residents would prefer to have outdoor terraces and courtyards inside their houses and buildings, as they feel that these features allow a high degree of social interaction with neighbours, and increase the interaction with the environment as it gives access to the natural light and ventilation. Although there is a trend of inserting a central atrium, it is not exposed to the daily life, so it seems to be lifeless.

Table 1. Social Problems in Apartment Buildings in MENA Region (Authors)

Social Indicators	Social Problems in Apartment Buildings in MENA Region	Percentage of Respondents
1. Security	- Current houses do not afford secure outdoor spaces for children	71 %
2. Social interaction	- There are limited spaces for social interaction with neighbours. To accommodate this problem, residents chat with neighbours: <ul style="list-style-type: none"> <li>o At the entrance of the building.</li> <li>o At the entrance of their apartment.</li> <li>o At the outside garden.</li> <li>o At the courtyard inside their building.</li> </ul>	86 % 45 % 12 % 13 %
3. Crowding	- Residents live in buildings that are crowded regarding number of apartment on each floor	62 %
4. Visual privacy	- Entrances are located directly opposite to each other, which destruct the privacy of the family members. - Residents cannot use terraces/balconies due to the lack of privacy.	86 % 31 %
5. Accessibility and hierarchy of spaces	- There are many paths and circulation spaces between apartments. - Entrances of apartments open directly on the main core of the building	54 % 75 %

### Exploring the Spatial Design of Residential Buildings in MENA Region

Social qualities of residential buildings could be explained through spatial configurations. This section aims to explore the spatial design of contemporary developments to address reasons of social problems presented in the previous section. Moreover, a spatial investigation for layouts of traditional neighbourhoods extends our understanding of the local culture and the different potentials of such precedents.

‘Spatial reasoning’ as a rigorous method for understanding the layout complexity, and exploring features that have social or experiential significance, has been adopted. Jerome

Bruner, in his studies about the psychology of knowing, defined 'reasoning' as 'going beyond the information given' (Bruner, 1973). For instance, tracing the visual fields from a certain location in a building allows a clear evaluation of spatial elements that affect the privacy of its occupants. To understand this complexity, two approaches have been adopted:

(1) Typological analysis, which involves categorizing components of designs that have shared characteristics according to predefined criteria (such as location, area, geometric properties, and patterns of arrangement).

(2) Syntactical analysis, which explores topological and social relations implicit in the architectural setting (Hillier and Hanson, 1984). Results extracted from this analysis are presented mathematically (control and integration values), which are useful for interpreting the social life and the overall configuration of selected cases (e.g., high integration values indicate that spaces are busy, more accessible, and less private). Two computational tools were used for carrying out syntactical analyses. Firstly, *Syntax2D*, to execute isovist analysis that addresses the visual fields of a person at one location of the environment (e.g., the main entry point of the neighbourhood, and from the entry point(s) of each house in the cluster) (Wineman et al., 2007). Secondly, *DepthmapX*, which is a 'Visibility Graph Analysis (VGA)' tool to understand the spatial configuration of the environment (Turner, 2001). VGA includes two types of tests: (i) connectivity analysis that creates visibility connections between all spaces; and (ii) agent analysis, which indicates patterns of movement, and the frequent use of spaces released from the public gathering space.

### ***Readings from Traditional Neighbourhoods and Contemporary Apartment Buildings***

A detailed typological analysis and a syntactical evaluation for four clusters of traditional houses and five apartment buildings, located in MENA region, have been conducted to assess the social quality of these arrangements. The layout of traditional neighbourhoods in the study area is usually characterised by organic spatial configurations with more than one focal centre, and a hierarchal system of open spaces. However, this irregularity of layouts produces a homogeneous urban fabric and balanced townscapes that are determined by specific social and cultural principles (Bianca, 2000). In contrast, the layout of contemporary residential buildings has one focal point, which is the main vertical core. In most cases, this space is considered the main gathering area for all apartments, which is attached directly to the entrance of residential units. The following illustrates results of analysis according to social indicators concerned by residents.

#### ***Social Interaction and Human Comfort***

The dense structure and the physical cohesion layout are prominent features of traditional clusters. However, open spaces, which constitute an approximately half area of the cluster (39% to 54%), offer a valuable element in such harsh environments and could reduce external heat gain or loss (Ragette, 2003; Moossavi, 2014). The spatial analysis shows that open public spaces form 21% to 38% of the cluster's area (see Table 2). Moreover, the percent of private courtyards relative to the total ground floor area of residential units represents 18% to 28%. These open areas invite the gathering of residents at various times of the day and on different levels. Also, such spaces allow social interaction at a family level in private courtyards; social interaction among women and children in cul-de-sacs and semi-private alleyways; and mixed interaction in public spaces (Eben Saleh, 1997).

On the other hand, semi-public and semi-private spaces in front of apartments in contemporary buildings are limited to circulation paths and constitute less than 10% of the floor area (see Figure 1). Moreover, open spaces (such as balconies, terraces or courtyards)

represent only 3% from the total area of residential units, which, therefore, affected degrees of social interaction among neighbours, and levels of human comfort inside the house.



Figure 1. Common gathering spaces and open areas in (a) a traditional residential quarter; (b) contemporary apartment buildings (Authors)

Table 2. Percentages of open areas, public spaces and courtyards in traditional neighbourhoods (Authors)

Case No. and Location	Total Area of the Cluster (m <sup>2</sup> )	Open Areas		Public Spaces		Private Courtyards	
		Area (m <sup>2</sup> )	%	Area (m <sup>2</sup> )	%	Area (m <sup>2</sup> )	%
CLUS-1 (Egypt)	1185	616	52 %	454	38 %	162	22 %
CLUS-2 (Iraq)	1642	885	54 %	622	38 %	263	26 %
CLUS-3 (Iraq)	1929	755	39 %	499	26 %	256	18 %
CLUS-4 (Syria)	4525	1856	42 %	929	21 %	759	28 %

### *Accessibility, Hierarchy of Spaces, Safety, and Security*

The access from public areas to residential units in traditional quarters is usually controlled and broken into hierarchical sections. Each group of courtyard houses is clustered around a small public space (a cul-de-sac), which varies in its width between 2.50 and 5.95 meters. These spaces are connected with main public spaces (width = 3.15 to 11.25 meters) through narrow-secondary alleys and pedestrian walkways (width = 2.25 to 3.50 meters) (see Figure 2). Syntactical analysis of such clusters shows that public spaces and courtyards have the highest connectivity values (as represented in Figure 2 with red/orange colours). This system prevents conflicts with the public realm, makes residents able to manage their desired rate of social contact, allows for children a secure place to meet and play with nearby neighbours, and at the same time maintains a balance between isolation and interaction (Mortada, 2003; Eben Saleh, 1997).

In contrast to the vernacular model, investigations at the scale of contemporary buildings show that there is a sudden transition from the vertical circulation core to the entrance of apartments, and from the entry point to the living area inside the house. Such issues have negative impacts on security and privacy of residents.

### *Visual Privacy*

Visual privacy could be defined as 'the ability to carry out everyday activities hidden from the eye of outsiders or without fear of being observed by them' (Al-Kodmany, 1999). Spatial designs of buildings should have the ability to regulate privacy according to the needs of users (Mustafa, 2010). At the scale of the cluster, traditional layouts offer better design



solutions regarding the location of entrances, which are arranged in a staggered pattern that protects family members from outside strangers (see Figure 3). Moreover, entrances are connected with a small semi-private space instead of a main public area. In the case of linear passageways, entrances are usually lead to a corner of a house, where there are no private activities. In contrast to these patterns, entrances in most current developments are located opposite to each other with no visual barriers in front of doors.

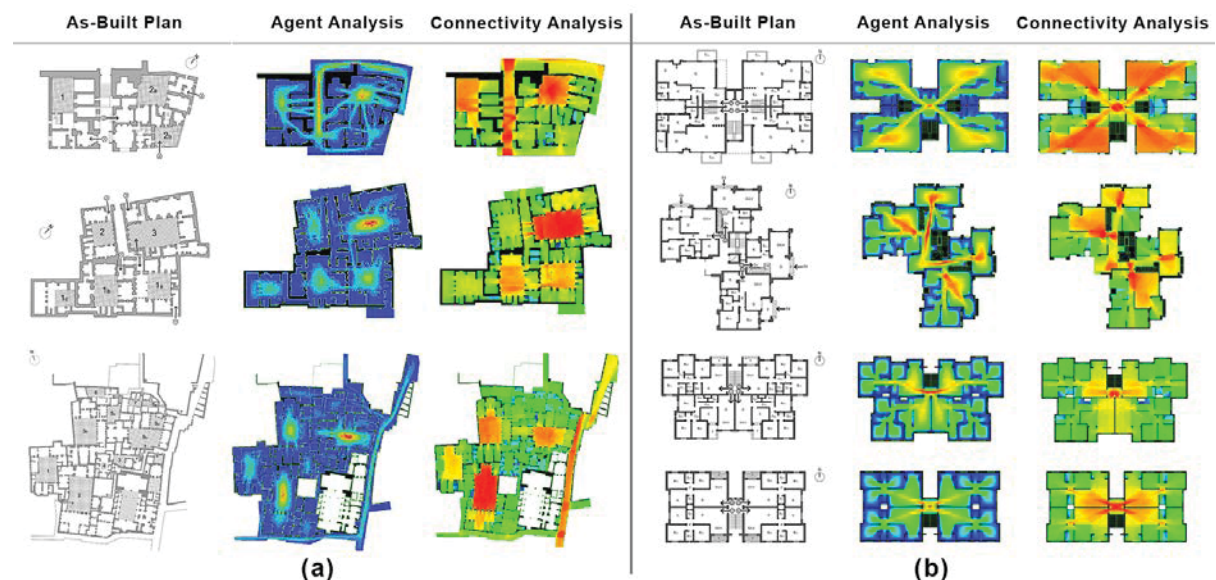


Figure 2. 'Agent Analysis', showing patterns of movement and the frequent use of spaces released from the main public space, and 'Connectivity Analysis', showing number of points that are connected visually to other spaces produced by 'DepthmapX 0.50' software: (a) in traditional residential quarters; (b) in contemporary apartment buildings (Authors)

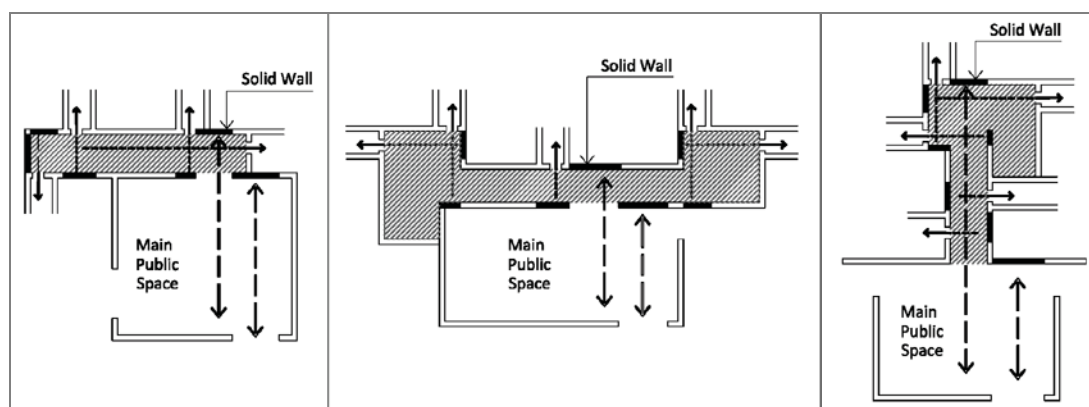


Figure 3. Strategies for achieving visual privacy in traditional neighbourhoods (Authors)

### Strategies for Designing a Socially-Sustainable Vertical Building

A successful design means that it has an 'identity', which relates to the design of all components in harmony with context, climate, needs, and requirements of the modern and future time (Mehrpooya *et al.*, 2015). Yet, a socially-sustainable high-rise building needs a sensitive approach that deals with social interaction and accessibility inside the building while maintaining the privacy of residents (Kennedy *et al.*, 2015).

One approach to deal with these issues is to incorporate the local tradition and its unique responses to spatial arrangement, place, and climate, in the design of contemporary buildings (Lim, 2004, as cited in (AlHaroun, 2015). This methodology generates a



'contemporary vernacular' architecture that has symbolic identities. Information gained from the analytical process showed that traditional clusters have many potentials that are useful for achieving a socially-sustainable environment. Ken Yeang, for example, bases his works on the adaptation of regional architecture 'a critical regionalism approach', through understanding traditional values, as well as the importance of progress, without the direct use of traditional forms and materials (Pomeroy, 2013). This way of thinking, which leads design to respond to specific context, is a balance between two views: the 'traditional' perspective, where designers see the loss of traditional ways and values, and the 'modern' perspective, where they declare the inevitability of change in the age of globalisation (Ragette, 2003).

Based on that, results extracted from traditional neighbourhoods are used to establish a database that identifies spatial elements and specific relationships. This database, associated with spatial requirements of high-rise buildings, is used to generate alternatives for vertical developments. On a basic level, the overall social qualities of such horizontal quarters could have the potential of being transferred into vertical arrangements by dividing it into segments, as a representation of neighborhoods in a traditional fabric. This solution could highly promote the concept of hierarchy and clustering that create a mutual responsibility for common spaces in each segment for encouraging interaction between neighbors.

Shape grammar, as a rule-based system for generating layouts, is used. This system, developed by George Stiny and James Gips in 1970s, has a bottom-up approach, which starts with generating an initial shape (Stiny and Mitchell, 1978). The framework for developing this shape to create a functional layout could be outlined in four stages. (1) defining vocabularies as main shapes (which represent spaces with specific properties); (2) determining spatial relationships; (3) formulating rules to be applied on forms; and (4) combining/articulating shapes through applying rules recursively, to define a language of design (Eilouti and Al-Jokhadar, 2007).

### ***Establishing a Parametric Socio-Spatial Grammar***

A residential cluster could be divided into two main zones: (a) common spaces, which represent the public zone that include gathering areas and corridors; and (b) residential units, which are the private zone for residents. Based on the typological analysis presented in the previous section, a socially-sustainable residential environment needs to include a hierarchal system of common spaces, which consists of: (a) a main public space (MPS); (b) semi-private spaces between residential units (PVS); and (c) pedestrian pathways (COR) that connect those two types. The total area of these spaces represents 21% to 38% from the area of the cluster. To increase the environmental benefits of such gatherings areas inside the building, it is useful to attach the main public space with one or two edges of the layout. In MENA region, this edge could be located on East, West, or South. However, semi-private spaces in front of apartments could be covered and considered as transitional/gathering areas.

To maintain a balance between isolation and interaction inside the residential unit, it is recommended to include a private courtyard for each house. There are different typologies for the location of such an introverted open space (see Figure 4). In high-rise residential buildings, the selection of appropriate typology is determined by two factors: (a) the location of the residential unit in relation to other units on the same floor; and (b) on which floor the apartment is located. For instance, a central courtyard could be sufficient on

top floors. However, a courtyard that is attached to one edge of the building is suitable on any floor of the building (see Figure 5).

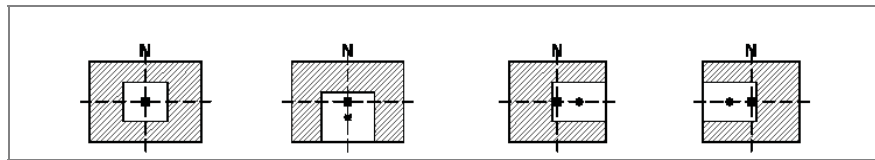


Figure 4. Typologies for the location of courtyards inside traditional houses (Authors)

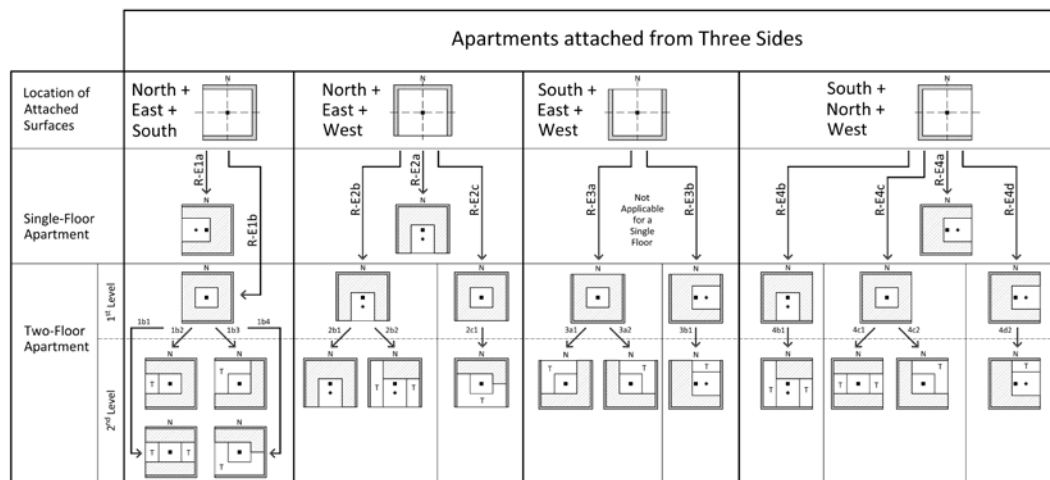


Figure 5. Sample of rules showing typologies of apartments and location of courtyards based on number of attached surfaces with other apartments on the same floor (Authors)

As creativity, flexibility, and adaptability are important issues that need to be addressed in the design process, a parametric design approach is incorporated in the construction of the grammar. Two characteristics are associated with such approach. Firstly, geometric properties and locations of design elements are defined through variables and parameters. Secondly, designers can revise parameters at any stage to modify their designs and generate different alternatives (Jabi, 2013). For this study, the following parameters are defined: (a) geometric configuration of common spaces and courtyards; (b) the percent of public and semi-private spaces relative to the total area of the building; and (c) orientation of common spaces and private courtyards. Accordingly, social qualities of spaces could be affected positively or negatively (see Figure 6). For instance, social interaction and human comfort could be enhanced by increasing the width of public spaces or private courtyards. However, these areas become more crowded and the security and safety of family and children might be decreased.

### Generating a High-rise Residential Building using a Computational Tool

The constructed grammar has been translated into a computational interface using 2D/3D CAD modeling software "Rhinceros 3D", with its plugin "Grasshopper", to generate solutions with a high degree of accuracy in a short time of execution. Grasshopper is a visual scripting tool that helps the design to process. It allows input data to be passed from one component to another via connecting wires. The design strategy adopted in this tool is to split the building into vertical segments. The maximum number of segments is six, and each segment could be reached up to five floors. The total number of floors that could be generated is 30 floors. The tool suggests a list of 10 procedural tasks that guide the designer

through an interactive interface to define parameters and conditions (see Table 3). For each space, designers have the ability to define geometric properties, and alternatives for the location of each design element, through selecting numbers, as input data, from ‘number sliders’.

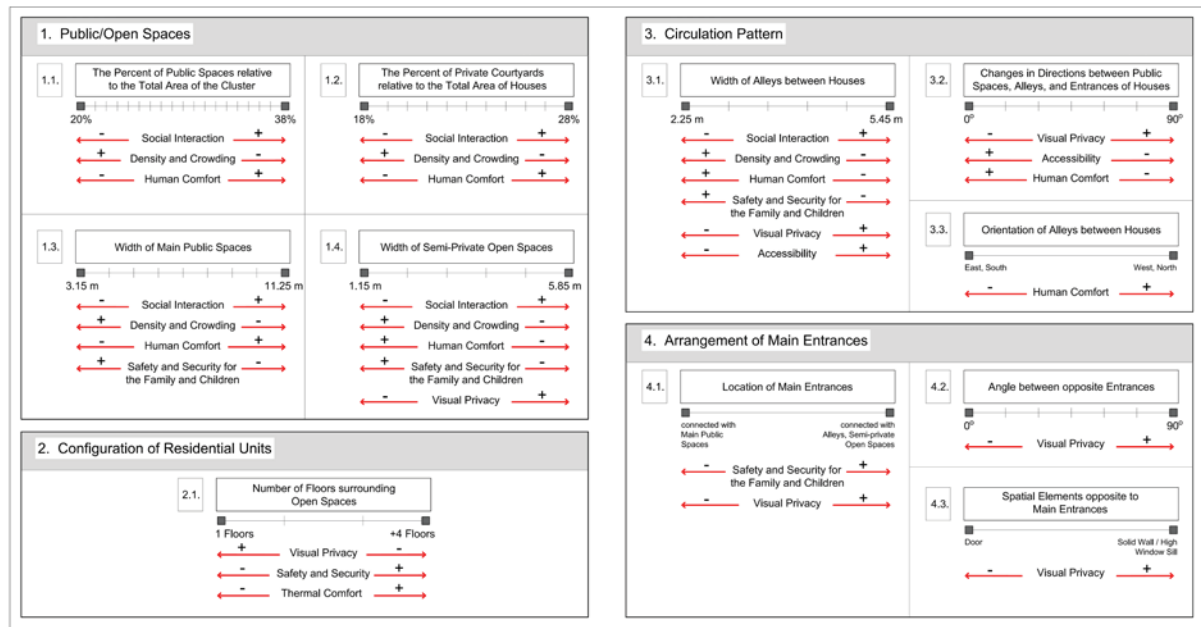


Figure 6. Parameters for main elements of design and how can affect qualities of social sustainability (Authors)

Table 3. Parameters and conditions for each task in the computational tool for generating a high-rise residential building (Authors)

Tasks and Stages of Design	Inputs (Parameters and Conditions)
1. Generating the allowable built-up area for the building	Width, length
2. Generating a vertical core (VC)	Width, length, height above roof level, location
3. Generating the main entry hall (EN)	Width, length, location
4. Generating the main public space (MPS) on the ground floor	Width, length, location
5. Generating a grid of structural columns	Size, distances between columns (x-axis, y-axis)
6. Generating corridors on ground floor (connecting EN, VC, MPS)	Width, location
7. Generating floors and main public spaces for each segment of the building	Height of each floor, number of floors on each segment, width and length of MPS on each segment, typologies for the connection of MPS with the outside
8. Generating semi-private spaces (PVS) between residential apartments	Width and length of corridors connected with PVS, width and length of PVS, location of PVS
9. Generating the layout of residential apartments	Maximum and minimum area of apartments on each segment, width and length of apartments
10. Generating courtyards for each apartment	Width, location

During the implementation of each task, two-dimensional plans for all segments and three-dimensional views of the design are presented. Moreover, the interface provides the user with overall calculations for the building, which include: total number of floors, total height of the building, total allowable built-up area, total area of common spaces, total area of residential units, number of apartments, detailed areas for each space, and percentage of area for each design feature from the total area of the building.

The tool has been tested to generate different solutions for high-rise buildings through modifying width, length, and location of each space. Figures (7) and (8) illustrate design alternatives for a 19-floor building and a 13-floor building, respectively, by changing number of floors on each segment of the design.

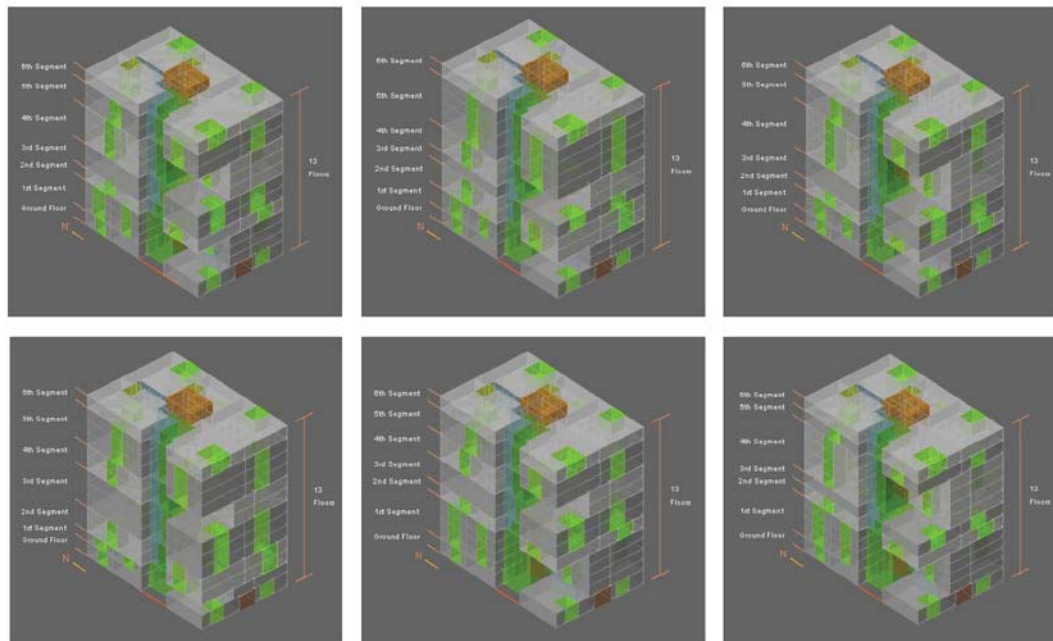


Figure 7. Six different alternatives for a 13-floor residential building generated by the developed parametric grammar, through changing number of floors on each segment of the building (Authors)

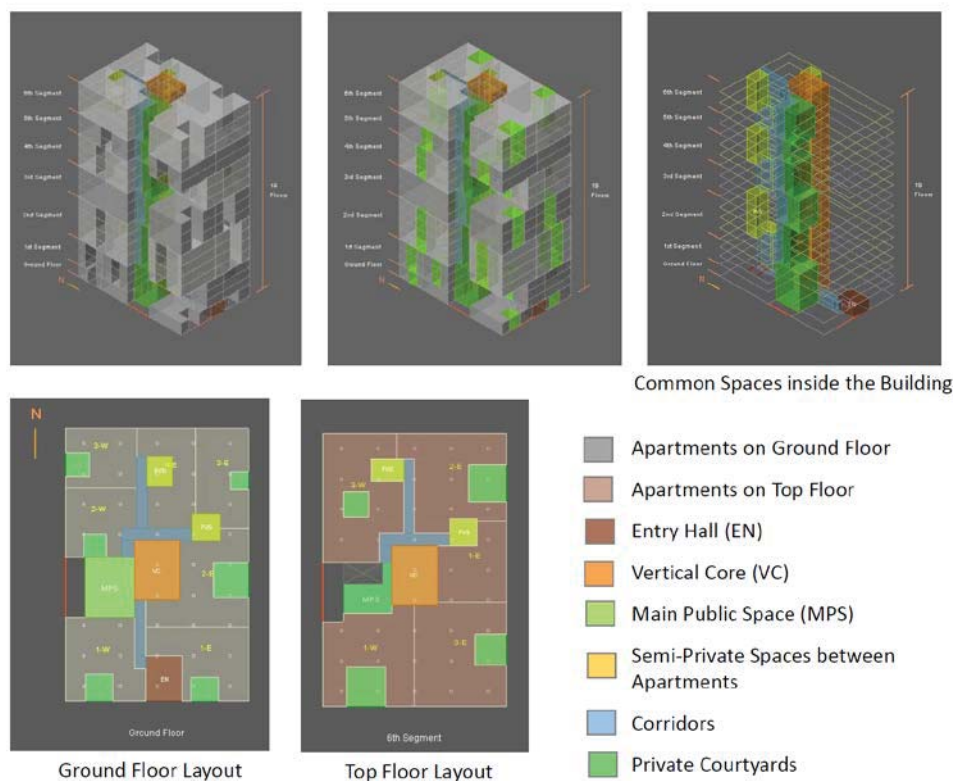


Figure 8. A 19-floor residential building generated by the developed parametric grammar, showing the hierarchy of common spaces and private courtyards (Authors)

## Reflections and Conclusion

Achieving social sustainability in residential developments requires a holistic approach for clarifying spatial qualities that affect the social life inside the building. Information gained from the analytical reasoning process for traditional neighbourhoods in MENA region could help designers in problem interpretation and the projection of extracted results into new alternatives. These factors create a type-based database that can be used to improve the social qualities of future developments. For instance, studying the location of each space, and measuring distances between functions, are useful for analysing accessibility and movement. Moreover, defining relationships between spaces offer information about their hierarchy, the degree of social interaction that takes place within them, and their ability to maintain the privacy of their occupants.

The proposed tool for designing a high-rise residential building, embodied in Rhino/Grasshopper, with the possibility of changing geometric and spatial parameters, offers an alternative method for implementing strategies of social sustainability, and at the same time adds flexibility to the generation process.

The spatial analysis for alternatives produced by the developed interface shows that common spaces inside the building represent 18% of the total area of the building. Moreover, private courtyards represent 11% from the area of residential units. Therefore, several rewards, for both residents and developers, could be achieved using the developed model. Regarding social benefits, the hierarchical system of spaces and the availability of gathering areas inside the building offer an attractive place for social relations and could increase the frequency of contact with neighbours. Moreover, these public courtyards alleviate the sense of overcrowding, and at the same time act as a buffer zone in front of the private domain of residential units, which could be used as playgrounds for children under the watchful eyes of their parents.

Regarding environmental benefits, courtyards inside the building are suitable areas for planting trees and shrubs, as they are open to the sun and the natural air. Therefore, this could offer thermal comfort for users, and reduce heat gain and energy consumption. In addition, different economic rewards, especially for developers, could be achieved. Public spaces inside the building and courtyards inside apartments are part of the rentable area and aid the selling of the apartment. Thus, there is a revenue with no loss area. Furthermore, there is an omission of corridor spaces, which constitute less than 5% of the total area of the building. Finally, there is a reduction in the number of fire doors, as the courtyard is part of the escape route, and the apartment is open to a well-ventilated access.

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## References

- Al-Jokhadar, A. and Jabi, W. (2016). Enhancing Social-Cultural Sustainability in Tall Buildings: A Trace from Vernacular Houses. In: Wood, A., Malott, D. and He, J. (eds.) *Cities to Megacities: Shaping Dense Vertical Urbanism. Proceedings of the CTBUH 2016 International Conference; China*. Chicago: Council on Tall Buildings and Urban Habitat, pp. 633–641.
- Al-Kodmany, M.K.A.-D. (1999). Residential visual privacy: Traditional and modern architecture and urban design. *Journal of Urban Design*, 4, pp. 283–311.



- Al-Masri, W. (2010). The Courtyard House in Kuwait Today: Design Approaches and Case Studies. In: Rabbat, N. (ed.) *The Courtyard House: From Cultural Reference to Universal Relevance*. Surrey, England: Ashgate Publishing Limited, in association with the Aga Khan Program for Islamic Architecture, pp. 203–222.
- AlHaroun, Y. (2015). *Contemporary Attitudes to Vernacular Elements in Kuwait's Domestic Architecture: A Mixed Method Study*. University of Sheffield, UK.
- Berkeley-Group and UK-GBC (2012). *Practical How-to Guide: How to Use a Social Sustainability Framework*. London.
- Bianca, S. (2000). *Urban Form in the Arab World: Past and Present*. New York: Thames and Hudson Inc.
- Bruner, J.S. (1973). *Beyond the Information Given: Studies in the Psychology of Knowing*. Jeremy, M. A. (ed.). New York: W W Norton & Co Inc.
- Crouch, D. and Johnson, J. (2001). *Traditions in Architecture: Africa, America, Asia and Oceania*. Oxford: Oxford University Press.
- Cuthill, M. (2010). Strengthening the 'social' in sustainable development: Developing a conceptual framework for social sustainability in a rapid urban growth region in Australia. *Sustainable Development*, 18, pp. 362–373.
- Dempsey, N., Bramley, G., Power, S. and Brown, C. (2011). The Social Dimension of Sustainable Development: Defining Urban Social Sustainability. *Sustainable Development*, 19, pp. 289–300.
- Eben Saleh, M.A. (1997). Privacy and communal socialization: The role of space in the security of traditional and contemporary neighborhoods in Saudi Arabia. *Habitat International*, 21, pp. 167–184.
- Eilouti, B.H. and Al-Jokhadar, A.M. (2007). A Generative System for Mamluk Madrasa Form-Making. *Nexus Network Journal*, 9, pp. 7–30.
- Hillier, B. and Hanson, J. (1984). *The Social Logic of Space*. Cambridge: Cambridge University Press.
- Hudgins, M. (2009). *High-Tech Engineering Helps Skyscraper Developers Reach Record Heights*. National Real Estate Investor.
- Jabi, W. (2013). *Parametric Design for Architecture*. London: Laurence King Publishing Ltd.
- Kearns, A., Whitley, E., Mason, P. and Bond, L. (2012). 'Living the high life'? Residential, social and psychosocial outcomes for high-rise occupants in a deprived context. *Housing Studies*, 27, pp. 97–126.
- Kennedy, R., Buys, L. and Miller, E. (2015). Residents' Experiences of Privacy and Comfort in Multi-Storey Apartment Dwellings in Subtropical Brisbane. *Sustainability*, 7, pp. 7741–7761.
- Mehrpoya, H., Khuonbazi, V. and Ahouei, S. (2015). A comparison of 'identity' in vernacular (traditional) and contemporary (modern) houses. *WALIA Journal*, 31, pp. 69–75.
- Modi, S. (2014). Improving the Social Sustainability of High-rises. *CTBUH Journal*. Council on Tall Buildings and Urban Habitat, pp. 24–30.
- Moossavi, S.M. (2014). Passive Building Design for Hot-Arid Climate in Traditional Iranian Architecture Climate of Iran. *Green Architecture and Arts Magazine*, pp. 1–20.
- Mortada, H. (2003). *Traditional Islamic Principles of Built Environment*. Oxon: RoutledgeCurzon, Taylor and Francis Group.
- Mustafa, F.A. (2010). Using space syntax analysis in detecting privacy: a comparative study of traditional and modern house layouts in Erbil city, Iraq. *Asian Social Science*, 6, pp. 157–166.
- Oldfield, P.F. (2012). *Tall Buildings and Sustainability*. University of Nottingham.
- Oxman, R. and Gu, N. (2015). Theories and Models of Parametric Design Thinking. In: *eCAADe 33*.
- Pomeroy, J. (2013). Internal Environment and Planning. In: Parker, D. and Wood, A. (eds.) *The Tall Buildings Reference Book*. Oxon: Routledge, pp. 123–132.
- Ragette, F. (2003). *Traditional Domestic Architecture of the Arab Region*. Sharjah, UAE: American University of Sharjah.
- Schwarz, M. and Krabbendam, D. (2013). *Sustainist Design Guide: How Sharing, Localism, Connectedness and Proportionality Are Creating a New Agenda for Social Design*. Amsterdam: BISPublishers.
- Serageldin, M., Larsen, M. and Summers, B. (2015). *World Migration Report 2015*.
- Stiny, G. and Mitchell, W.J. (1978). The Palladian grammar. *Environment and Planning B*, 5, pp. 5–18.
- Turner, A. (2001). Depthmap: a program to perform visibility graph analysis. In: *Proceedings of the 3rd International Symposium on Space Syntax*. Atlanta, pp. 7–11.
- Wineman, J., Turner, J., Parra, S., Jung, S.K. and Sense, N. (2007). Syntax2d: an open source software platform for space syntax analysis. In: KUBAT, A. (ed.) *Proceedings of the 6th International Space Syntax Symposium*. Istanbul Technical University, Istanbul, Turkey, pp. 23–26.
- Woodcraft, S. (2012). Social Sustainability and New Communities: Moving from Concept to Practice in the UK. *Procedia - Social and Behavioral Sciences*, 68, pp. 29–42.
- Yeang, K. (2012). *A Vertical Theory of Urban Design*. Available at: <http://www.buildingfutures.org.uk>.



# "Reimagining sustainable design" A critical comparative analysis for sustainable design approaches and results.

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**Abstract:** This paper aims to re-image the understanding of sustainable design practice. It classifies sustainable design philosophy in the built environment into two approaches of different results. The first approach is of quantitative measurements i.e. points of design that can achieve measurable credit points. The second approach is a qualitative one that seeks qualitative values of design such as beauty, social respect, physiological comfort and other similar points. The research will introduce two terms under which sustainable design approaches can be classified. The first term will be introduced as quantitative approach for sustainable design and assessment (QN.A.S) and the other will be qualitative approach for sustainable design and assessment (QL.A.S). The reason for this classification is that Sustainable design criticism rating systems are mostly based on quantitative scores with less regard to qualitative aspects and variables. Through this new classification the research would offer scientific possibilities to re-evaluate sustainable current design practice results; and through comparative analysis the research will offer two complementary models for the values of sustainable design quantitatively and qualitatively which can end with a new vision for criticizing sustainable products.

**Keywords:** Sustainable design, Qualitative sustainability, sustainability criticism.

## Introduction

Modern sustainable movement has its roots back to the second half of the twentieth century. Thoughtful individuals, writers and organizations were concerned with the environmental degradation. Their writings such as 'Earth Spaceship' in 1965 by Kenneth E. Boulding (Boulding, 1966) or "Zero Growth Formula" and "Limits to Growth" in the early 1970's (Meadows *et al.*, 1972) and others; all were the first warnings for the great danger mankind would face due to the massive consumption behaviour. They assumed that it would lead to a misbalance between needs and available resources which by default would lead to unpleasant change in the ecosystem balance.

Since the seventies and after the oil crisis, many steps were held forward for the ground basis of sustainable movement. A step forward took place with the progressive work of the WCED "world commission on environment and development" lead by Gro Harlem Brundtland that resulted in coining of the term sustainable development in the remarkable report of "Our Common future" in 1987. Sustainable development was defined as:

*"Sustainable development is the development that meets the needs of the present without compromising the ability of the future generations to meet their own needs"* (Brundtland, 1987).

Over the last decades, there has been many efforts to shift the sustainable movement steps forward; Some efforts were held by individuals like in case of Van Der Ryn, Amory Lovins and other early volunteers (McLennan, 2004), some others were led by national and International organisations through events and conferences held to discuss the future of sustainability. For the moment, there are several trials and critical studies done for the continual enhancement and improvement of the movement.

Sustainability is widely defined through three major pillars; environmental, social and economic pillars .There are various models for understanding their interrelation .The most famous one is known as the Three pillars Venn diagram model (Murphy, 2012),(University, 2011).

Through various theoretical writings and practices. there are two major points of view in understanding sustainability .The first one has its concerns related to ecology ;which means preserving the environmental balance. The second one is much more concerned with humanity better quality of life with in terms of productive capacity preservation (Solow, 1993) .Both perspectives rests on either economic vitality or environmental health with less regard to the Social sides which would result in achieving partial sustainability. The reason is that the social side of sustainability encompasses more complicated variables that are not easily measured or assessed .This requires a special study side by side with the other two perspective.

The social pillar as being related to humanities requires lots of quantitative studies. Paying more attention to this side of sustainability results in improving the current approaches and practices .

### ***Objectives***

This research aims to re-image the understanding of sustainable design practice through explaining two complementary values when approaching or criticising a certain design from sustainable point of view .one of these two values is quantitatively measured, while the second one is determined qualitatively .both together can truly be a method for developing of the current tools for assessment for sustainable design

### ***Methodology***

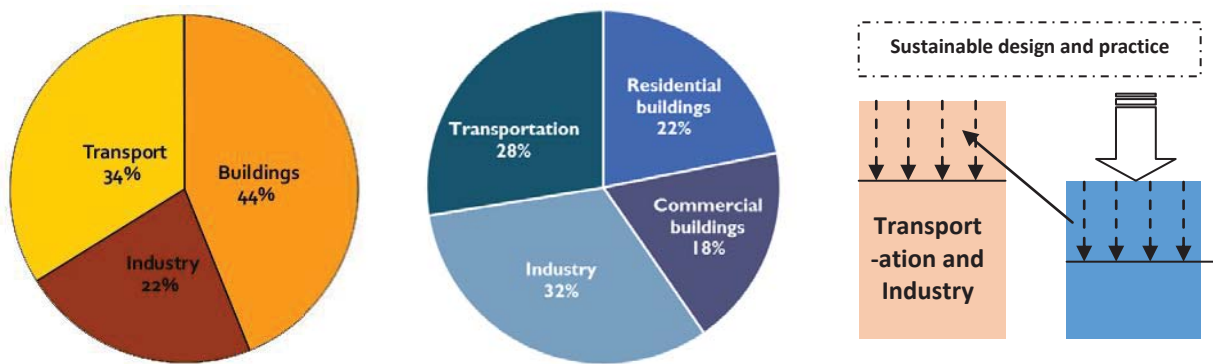
The research is based on the deductive critical analysis of literature archival data. The body of the research will focus on qualitative interpretation for the studied with descriptive explanatory discussion for the results.

The research is divided into two major parts the first one focuses on the study of the process of design and assessments in terms of sustainability. The second part is concerned with the re-imaging of the current sustainable practice.

### **Design for sustainable built environment**

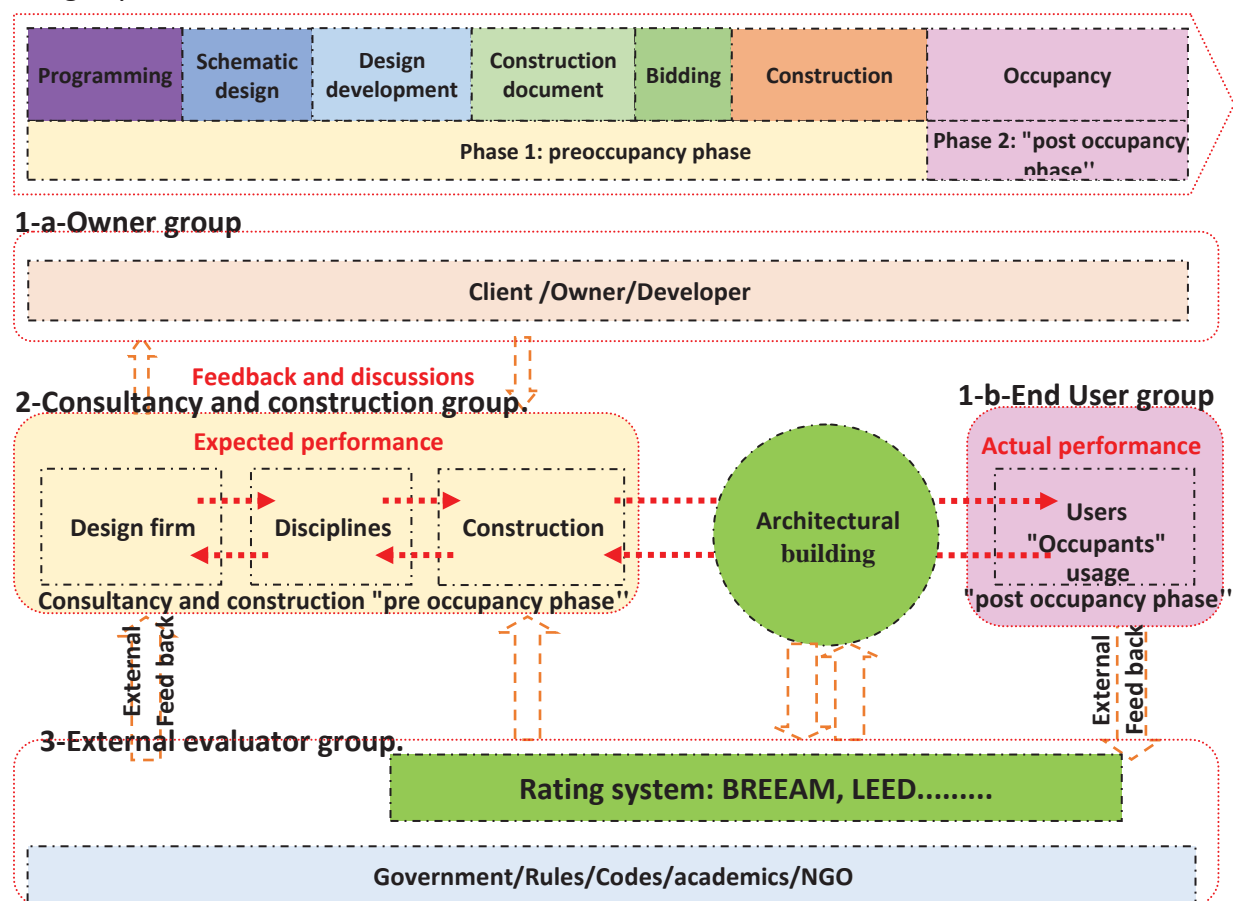
Buildings represent a major element in the built environment ,According to many statistics for total energy consumption in the last 10 years from 2008 for residential and commercial buildings, it seems that it consumes up to 40% of the total energy while the rest is consumed by the industry and transportation sectors .This means that at least proper orientation of architectural practice can help in the reduction of the 40% directly and should have an impact on the other 60% indirectly by the reduction of the building construction and industrial sector at least(Bcapcodes.org, 2017)

That's why it's obvious that the current practice is shifting gradually toward more sustainable designs. The aim is to target better qualities for the built environment.



### 3. Design Process in terms of sustainability

The author provides a flow chart that describes in an abstract way how buildings are being design and constructed with regard to issues related to sustainability. This diagram is based on previous work of the AIA project check list and the British Columbia law institute "anatomy of construction project "(Bcli.org, 2017).This diagram describes the general process without dealing with specific detailed actions and will be called as the " sustainable design cycle ".



As seen above the author divides the creation of any structure or architectural building into two major phases as follow:

- **The preoccupancy phase:** This phase is the phase in which the building is still unoccupied. It starts with the early design stage where the building is still a concept, and ends when the building is ready for being occupied. this phase passes by several stages encompassing design concept, design development, tender documents preparation, execution and construction.(Ucop.edu, 2017) In this phase there are key players; the author divided them into three groups. The owner group, the consultancy and construction group and finally the external evaluator group. The owner group role is initial as being the founder and the owner of the building which is being constructed according to his needs; in some cases the owner is the end-user or the occupant of the building. The role of the consultancy and construction group is the central role(LOS ALOMOS NATIONAL LABORATORY, 2002) as it links the owner/user's needs to the possible solution that can be achieved according to standards, rules and regulation prerequisite by the third group which is external evaluator group.
- **The post occupancy phase:** This phase is the phase in which a real building exists and is occupied. This phase represent the true performance of the design. This phase is so much important to be evaluated in terms of future enhancement for the coming projects and in order to adjust any negative points within the design if possible. In this phase the key players changes where the consultancy group is replaced by the End user group. In some cases as mentioned above the End user can be the owner himself.

In case of approaching a sustainable building, rating system assessment is classified under the third group side by side with other regulations and standards. It plays an important role in maintaining a proper process for achieving a sustainably oriented design specially before being constructed. For this reason putting sustainability as a major concern from the early stage of phase one at the schematic design stage can help in the reduction of cost and time for all other groups and can result in better sustainable design process.

### Rating systems in sustainable design

Green buildings are those which are designed and constructed through a process that has less damaging impact on the environment compared to other processes.(Corporation, 2010)

At the moment there are different bench marks for the rating and assessment of green buildings. BREEAM and LEED are two of the most famous leading rating systems in the world (Corporation, 2010). The philosophy of rating system is to assure that the design and constructed building meets at least the minimum requirements for being sustainable. Each benchmark has its own rating categories and grading.

Reaching the highest quality of evaluation doesn't guarantee being truly sustainable but it assures that most quantitative measures for sustainability are being achieved. for that reason buildings through this process are labelled as green buildings.(Mcdilda, 2008)(McLennan, 2004) .

By referring to Figure 2 , rating systems are classified under the external evaluator group .The reason for this classification is that common practice for respectable number of design firms doesn't encompass green design as an original standard of the schematic design stage. Instead, it put great role on technology as a "**technological fix**" for the design proposed in order to achieve sustainability credits or goals. Even if the consultancy and construction group takes all measures related to sustainability in consideration from the early schematic design stage , rating benchmarking for green designs is still required to be a

third party in order to assure that the consultancy and construction group meets the requirement for green design. The diagram (see Figure 3) shows the relation between group 2 and group 3.

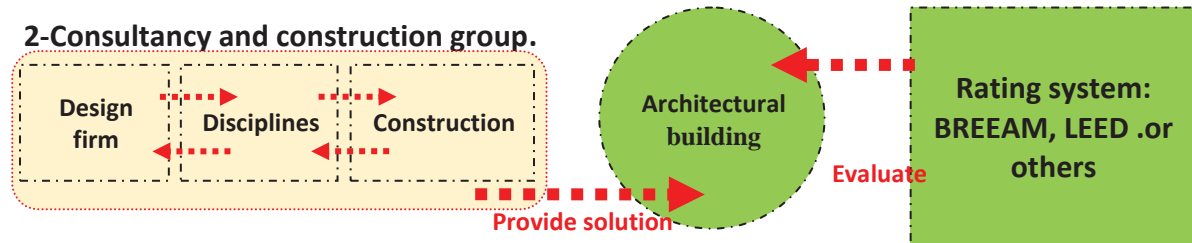


Figure 3 : Evaluation  
Ref: (author, 2017)

### Origins of green rating

The philosophy of green rating systems have common roots. These roots can be classified into six major basic principles as follow(Khalil, 2015)

#### ***Optimize Site Potential:***

The basic Idea of this principle is to respect aspects of the site potentials. Building projects begins properly with a proper site selection. There are different concerns with site potential which may include the reuse or rehabilitation of any site existing buildings. Optimizing site potential includes the study of site regional properties with regard to location, orientation and other regional aspects. Also it gives great regards to the study of project impact on the ecosystem, transportation methods, and site proper energy management.

#### ***Optimize energy use:***

The basic Idea of this principle is concerned with a careful management of energy use.it focuses on using alternative sources for renewable energy with regard to the reduction of energy loads and the increase of energy usage efficiency. This principle also encourages the increase of energy independence on public networks and zero energy building strategies.

#### ***Protect and conserve water:***

The basic Idea of this principle is the careful management of fresh water as a valuable and precious resource. It focuses on the reuse and the recycling of water. Efficient management of water requires feasible strategies and techniques for supplying transportation and treatment of water according to use.

#### ***Optimize building space and material use:***

The basic idea of this principle is about balance between need and available resources .It focuses on the intelligent use of materials that provide maximum efficiency with lower impact on the environmental balance. Strategies of the usage of nontoxic and recycled materials is essential as a method for optimization.

#### ***Enhance indoor environmental quality (IEQ):***

The basic idea of this principle is the physical comfort of occupant in terms of health, productivity, acoustic, daylight and thermal qualities for spaces.

### ***Optimize potential and maintenance practices***

The basic idea of this principle is to put building' operation and maintenance in consideration from the early stages of design. Plans for maintenance is essential for a good life cycle and life time for building as a constructed resources. This has direct impact from economic point of view on the cost and resources loss.

### **Green bench mark Evaluation and end result**

Green rating systems are systems that quantitatively evaluate buildings. The reason for calling them green rating systems is that they rest on either environmental health or economic vitality which are partial pillars of sustainability. The origin of this goes back to the two points of view mentioned above in the introduction the ecological point of view and the economical point of view, both focus on limits and resources in a quantitative way .The first point of view measures environmental balance while the other one measures feasibility of resource management. Social and culture pillar regards less consideration in such assessment methods. For this reasons process or building evaluated through this rating processes are not necessarily sustainable although they are green(McLennan, 2004). Which means that rating systems covers the quantitative measures regarding sustainability and witness a gap in measuring the qualitative values of it.

Referring back to the cycle of "sustainable design diagram" the consultancy and construction group are required only to provide quantitative evidence of building performance which are not enough for the success of the building users post occupancy.

### ***Current philosophy of green rating.***

The research will focus on both BREEAM and LEED as being the top leading rating systems. The following table provide a comparison between both rating systems with regard to schemes and categories(USGBC, 2016),(BRE Global Ltd, 2011)

Table 1 BREEAM and LEED's basic schemes and categories

System	Year established	Country of origin	Buildings certified	Rating schemes	Certification levels	categories
BREEAM	1990	United Kingdom	More than 250,000	<ul style="list-style-type: none"><li>• BREEAM New Construction:</li><li>• BREEAM International New Construction</li><li>• BREEAM In-Use</li><li>• BREEAM Refurbishment</li><li>• BREEAM Communities</li></ul>	<ul style="list-style-type: none"><li>• Pass</li><li>• Good</li><li>• Very Good</li><li>• Excellent</li><li>• Outstanding</li></ul>	<ol style="list-style-type: none"><li>1. Management</li><li>2. Health and Wellbeing</li><li>3. Energy</li><li>4. Transport</li><li>5. Water</li><li>6. Materials</li><li>7. Waste</li><li>8. Land Use and Ecology</li><li>9. Pollution</li><li>10. Innovation</li></ol>



LEED	1998	United States	More than 103,000	<ul style="list-style-type: none"> <li>• Building Design &amp; Construction (BD+C).</li> <li>• Interior Design &amp; Construction (ID+C).</li> <li>• Building Operations &amp; Maintenance (O+M).</li> <li>• Neighborhood Development (ND), and Homes.</li> </ul>	<ul style="list-style-type: none"> <li>• Certified</li> <li>• Silver</li> <li>• Gold</li> <li>• Platinum</li> </ul>	<ol style="list-style-type: none"> <li>1. Sustainable Site,</li> <li>2. Location and Transportation</li> <li>3. Energy Efficiency</li> <li>4. Water Efficiency</li> <li>5. Materials and Resources</li> <li>6. Indoor Environmental Quality</li> <li>7. Management</li> <li>8. Innovation and Added Value</li> <li>9. Regional priority</li> </ol>
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As seen above in the table there are common categories between both BREEAM and LEED. In the diagram below the author works on connecting rating system roots to both BREEAM and LEED categories. Though this diagram the philosophy of rating systems can be simplified into three forms of actions: the optimization action, the enhancement action, and the protection action. These actions verify the philosophy of quantitative measures of design, and the author will call them actions of measuring design sustainable performance. Which is an original core of sustainability. This model of assessment will be coined as quantitative sustainable design assessment tool and covers the quantitative sustainable design approach (QN.A.S).

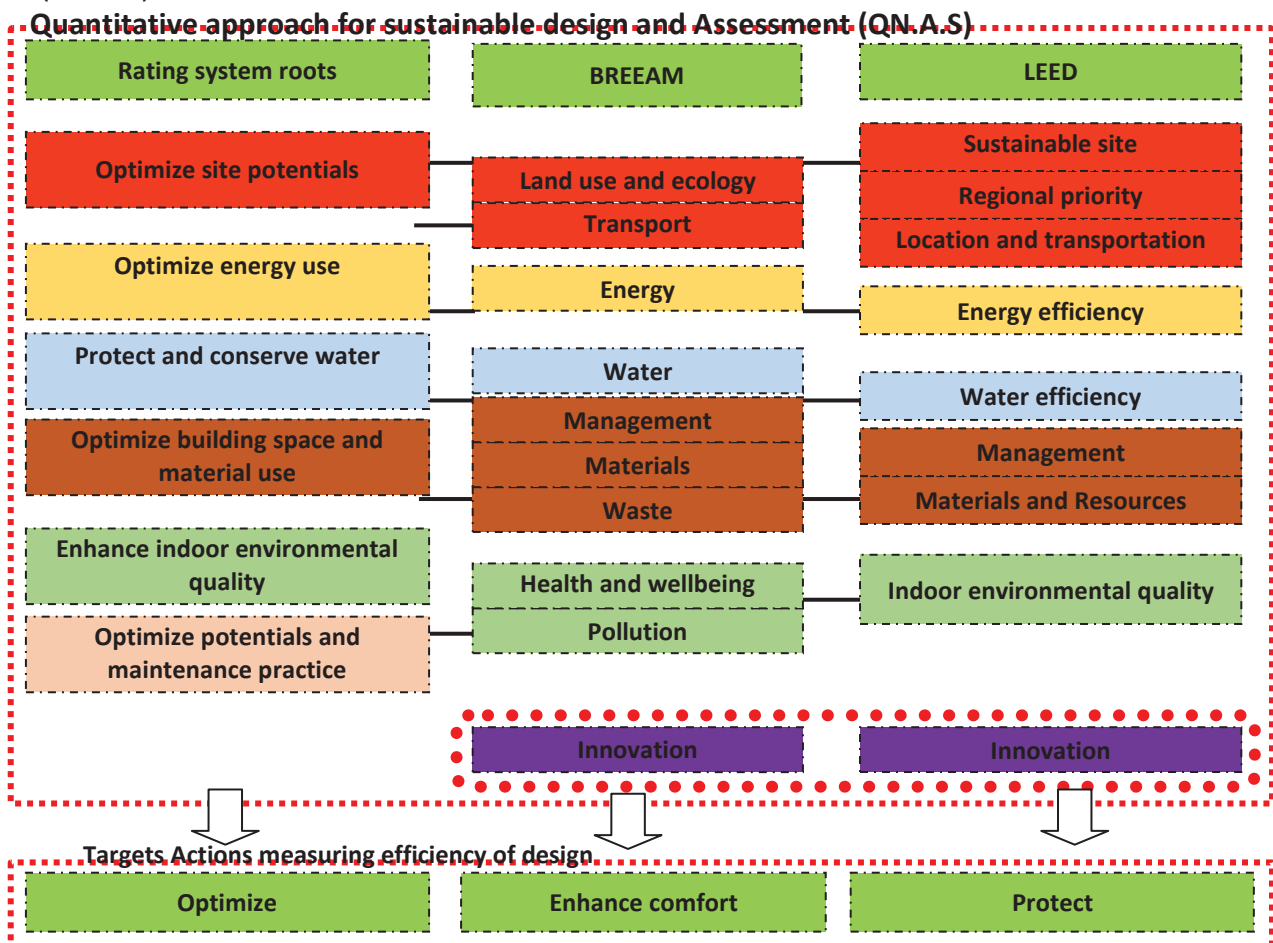


Figure 4: Current model for sustainable design approach and assessment  
Ref: (author, 2017)

### Introducing a qualitative approach for sustainable design

Through the previous study the research tries to introduce a second dimension for sustainable design approach and assessment. This research will introduce the basic philosophy, principles and guide lines for this approach for further research work and enhancement.

As mentioned above the current model for sustainable design and assessment seeks the measurable quantitative aspects of design which is performance of design. complementary model will seek qualities of design which is approached through three forms of actions. These forms of actions are called "qualitative target actions" and are as follow:

1. Social satisfaction.
2. Culture improvement.
3. Visual and aesthetic relaxation.

These actions will have direct connections with social wellbeing, personal wellbeing and personal relaxation which represents dimensions of physiological comfort. The following diagram explains the correlation between the three actions.

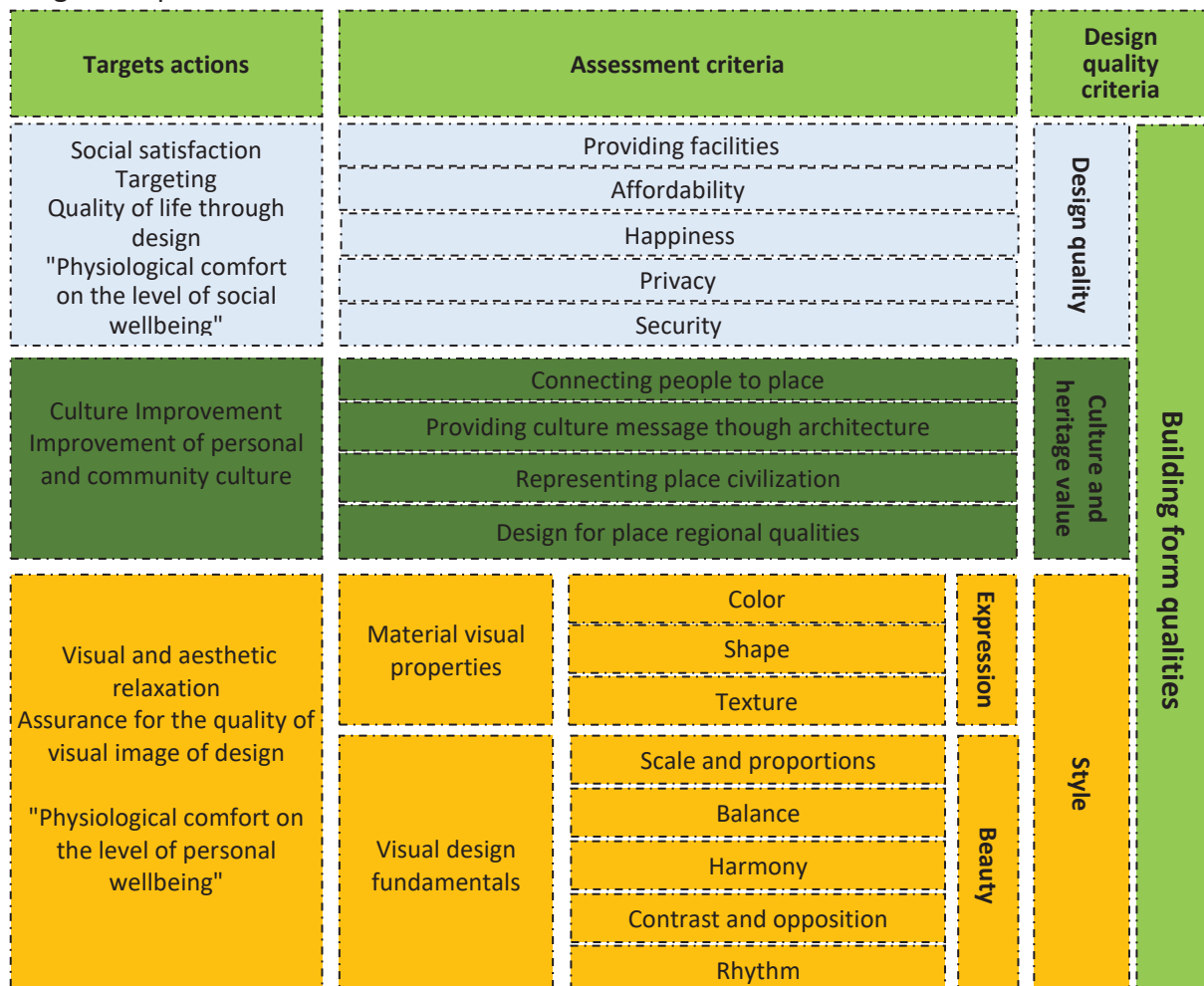


Figure 5: **Qualitative approach for sustainable design and Assessment (QL.A.S.)**

Ref: (author, 2017)

The following diagram is still primitive and through further research work on each target a strategic frame work for assessment can be provided which can add new dimensions for

current sustainable assessment methods and can help in enhancing sustainable design approaches.

## Results and discussion

The following diagram summarises the correlation between the two approaching models for sustainable design and assessment. As seen below the diagram is based on a triangle having its corners the three major pillars for sustainability where their intersection represents sustainable development. There are three quantitative actions which are the target actions of efficiency (see Figure 4).these actions are linked to quantitative principles of sustainable design (see Figure 5).and each actions represent a concern of one of the three pillars as shown. The "Enhance comfort" and "protect" actions are common between both qualitative and quantitative measures as they are expanded to qualitative levels known as "qualitative target actions" that seeks qualitative values of design.

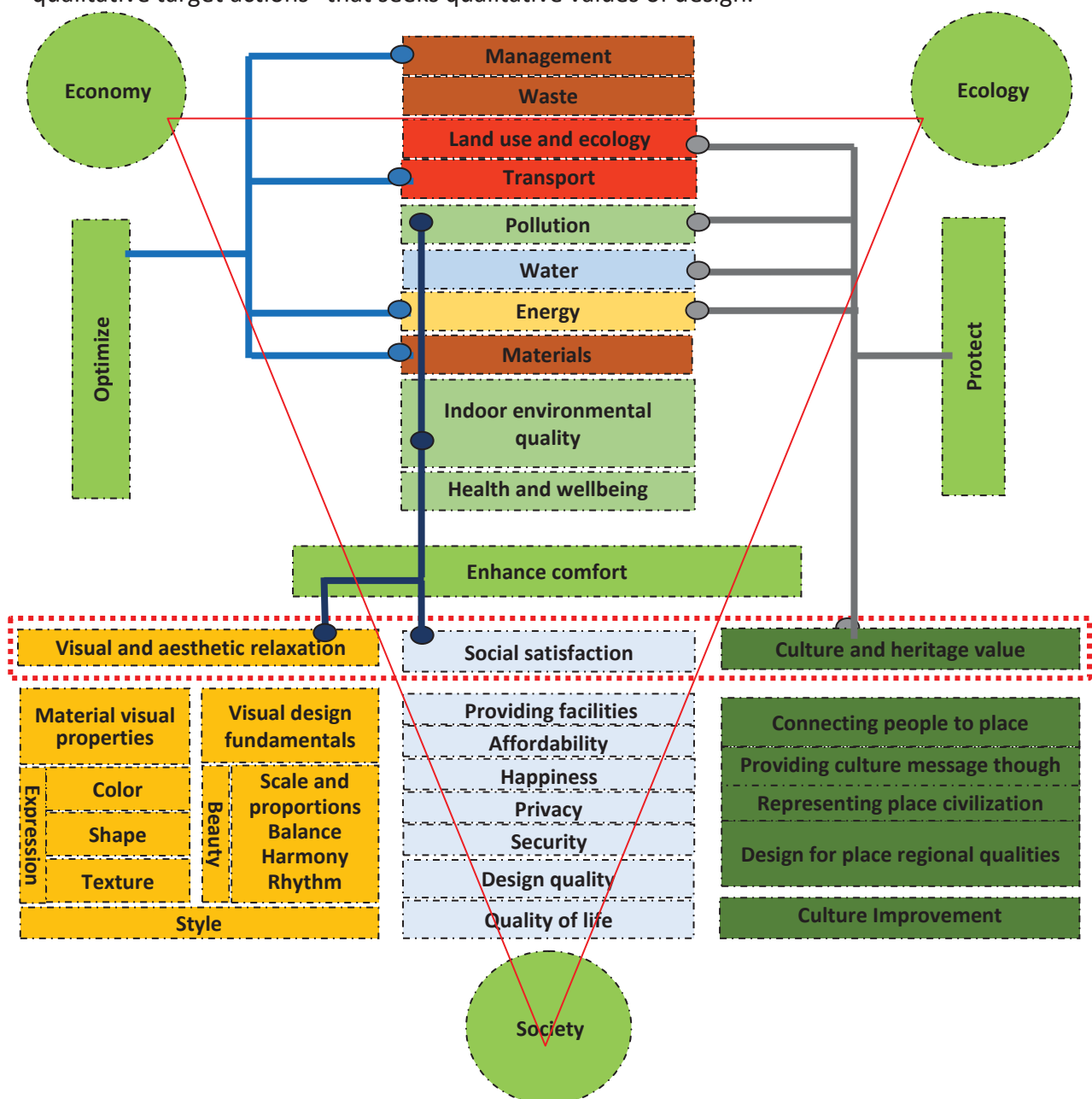


figure 6 The correlation between the two approaching models for sustainable design and assessment  
Ref: (author, 2017)

As seen this new diagram represents the starting point toward re-imaging sustainable design. This diagram is still in its primitive phase, continuous research work can transform the diagram from its theoretical base into action. Rating system could get use of the qualitative approach in enhancing the existing models of assessment. Through expanding the reward of innovation category to encompass more about qualitative measures of sustainable design.

## conclusion

The current approach for sustainable design and assessment is mainly based on quantitative measures and evidence which is an important part to cover the economic and environmental concerns related to sustainability. An additive quantities approach is proposed to be integrated to the dimension of the current sustainability model in order to cover the social side of the sustainable practice. This new re-imaging proposal can work as a starting point for developing the current approaches in sustainability.

## References

- Bcapcodes.org (2017) *Climate Change | The Building Codes Assistance Project*. Available at: <https://bcapcodes.org/topics/climate-change/> (Accessed: 25 September 2017).
- Bcli.org (2017) *Chapter 2 | British Columbia Law Institute*. Available at: <https://www.bcli.org/law-reform-resources/builders-lien-act/chapter-2#2.1> (Accessed: 25 September 2017).
- Boulding, K. (1966) 'Earth as a Spaceship', *Washington State University Committee on Space*. Available at: <http://earthmind.net/earthmind/docs/boulding-1965.pdf>.
- BRE Global Ltd (2011) 'BREEAM New Construction - Non-Domestic Buildings - Technical Manual', *Watford: BRE Global*, (3), p. 451. doi: SD5073-1.0:2011.
- Brundtland, G. (1987) 'Report of the World Commission on Environment and Development: Our Common Future', *Oxford paperbacks*, Report of, p. 400. doi: 10.2307/2621529.
- Corporation, B. S. (2010) 'Towards Sustainability : Green Building , Sustainability Objectives , and Building America Whole House Systems', *Towards Sustainability: Green Building, Sustainability Objectives, and Building America Whole House Systems Research Building*.
- Khalil, H. A. E. E. (2015) *Energy efficiency in the urban environment*.
- LOS ALAMOS NATIONAL LABORATORY (2002) 'chapter4: The Building Architectural Design', in *Renewable Energy*, pp. 48–79.
- Mcdilda, D. G. (2008) *365 Ways to Live Green, Thinking*.
- McLennan, J. F. (2004) *The Philosophy of Sustainable Design: The Future of Architecture*. Available at: [http://www.google.com/books?id=-Qjadh\\_OleMC](http://www.google.com/books?id=-Qjadh_OleMC).
- Meadows, D. et al. (1972) *The Limits to Growth*.
- Murphy, K. (2012) 'The social pillar of sustainable development : a literature review and framework for policy analysis', *Sustainability: Science, Practice, & Policy*, 8(1), pp. 15–29. doi: 10.1007/978-94-007-4854-5.
- Solow, R. (1993) 'An almost practical step toward sustainability', *Resources Policy*, 19(3), pp. 162–172. doi: 10.1016/0301-4207(93)90001-4.
- Ucop.edu (2017) *Project Design Phases | UCOP*. Available at: <http://www.ucop.edu/construction-services/facilities-manual/volume-3/vol-3-chapter-1.html> (Accessed: 24 September 2017).
- University, T. (2011) *EFQM framework for sustainability*. Available at: [http://cataleg.uji.es/record=b1417341~S1\\*cat](http://cataleg.uji.es/record=b1417341~S1*cat).
- USGBC (2016) 'LEED v 4 for NEIGHBORHOOD DEVELOPMENT', p. 161. Available at: [http://www.usgbc.org/sites/default/files/LEED\\_v4\\_BDC\\_04.05.16\\_current.pdf](http://www.usgbc.org/sites/default/files/LEED_v4_BDC_04.05.16_current.pdf).

# Defining the Characteristics of Design Process Models as a Basis for Proposing a More Sustainable Integrative Approach

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**Abstract:** Current architectural design process has proved unsustainable when it comes to coordinating various tasks among the different disciplines. Even sustainable architecture approaches- which largely advocate the need for an integrative process- have no explicit recorded evidence in extent literature with regards to the associated process. Sustainable architectural design has mainly been associated with the final product, i.e. the building, rather than the integrative process.

Based on the concept of a sustainable building requires a sustainable process; this research introduces a comprehensive critical analysis of current design processes to determine and define major characteristics of an integrative design process.

**Keywords:** Design process model, Architectural design, Integrative design process

## Introduction

Current architectural approaches have faced many challenges which urged the need to shift the way of developing our built environment and to achieve a whole integrated system design.

As developing integrative design process model for sustainable architectural design does not mean to start from scratch, the fragmented existing work should be consolidated.

This research is based on a comprehensive literature study of the characteristics of design process model with special focus on process models related to architectural design. This includes a comparative analysis of generic design process models and their classification schemes and structures, and goes on to make comparisons between developed architectural design process models. The identification of various common characteristics has the potential to help support a move towards improved coordination and, in time, integration between different design-based disciplines.

## Design Process Definitions

Design process composes of several distinct activities within its structure, each activity having a defined start and end. The structure of any process can be defined as an entire system of relationships which arrange the sequence of interlinked activities conceived according to a specific criterion (Tarnowski, 1986). This was related to the definition provided by Zeisel that design process is a well devised complex activity contains a series of distinct elementary activities of imaging, presenting and testing (Zeisel, 1984).

Another approach has defined the design process as a protocol which provide a common set of definitions, documentation and procedures that provide the basics to allow a wide range of organizations involved in a construction project to work together seamlessly. Hence, the process protocol maps the entire project process from the client's recognition of a need to operations and maintenance (Kagioglou, 1998).

Lawson B. described the design process as an activity of analysis, synthesis and evaluation involved in negotiating between design problem and solution (Lawson, 1997), while Jones, J. C. concluded that the design process attempts to resolve the conflict that exists between logical analysis and creative thought (Jones, 1984).

On the other hand, many approaches have focused on design process modeling. For instance, Eisenbart et. al. highlighted design process modeling as an activity to capture patterns that describe the behavior of processes (Eisenbart, Gericke, & Blessing, 2011). Design process models are introduced as an important means for the representation of design information in product development processes. Designers use design models to visualize and communicate their ideas to other members of a design team, the project manager or a costumer.

Austin, Baldwin, Li and Waskett have defined design process model as a conclusion of the planning methodology with an analytical design planning technique (Austin, 1999). Roozenburg and Eekels summarized the role of the design process model as a fundamental tool of problem solving (Roozenburg, 1995).

Wallace, K. explained that the engineering process model in general is a physical structure which can provide sufficient information and techniques to fulfill manufacture, assembly and testing requirements (Wallace, 1990).

Accordingly, a comprehensive definition of the Design Process Model (DPM) can be proposed as: "A tool to visualize an entire system of relationships among interlinked activities. This tool allows a wide range of interdisciplinary organizations to integrate their efforts and unify their goal towards an optimum, integrated, and iterative design process".

## Design Process Principles

Various principles have been defined through literature to characterize design processes. A summary of the introduced principles is presented as follows:

Table 1: Design Process Principles

Adapted from (Rachel Cooper, 2011), (Maier & Störrle, 2011), (Gericke & Blessing, 2012), (Howard, Culley, & Dekoninck, 2008)

	Development					Interaction			Product		Formality		Pragmatic			Flexibility					
	Creative	Complex	Iterative	Ill Defined	Holistic	Consistent	Process	People	Organization	Technology	Market	Legislations	Automatable	Conceptual	Standardized	Eco-system	Tools	Notations	Scalable	Customizable	Evolutionary
Cooper, 2011					●	●	●	●	●											●	
Maier et al, 2011		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Gericke et al, 2012	●		●		●	●	●	●	●	●	●									●	
(Howard et al, 2008)	●	●	●		●	●		●									●			●	




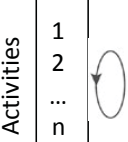
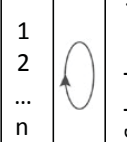
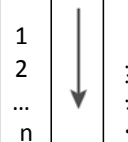
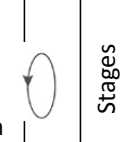
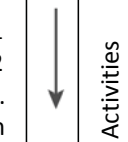
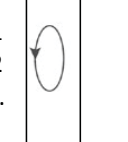
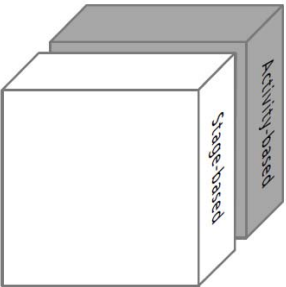
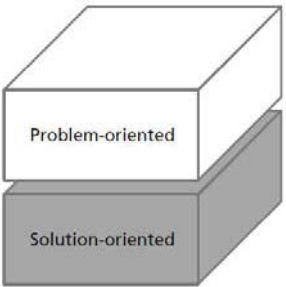
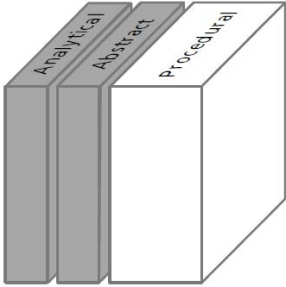
The schedule shows that some principles are commonly agreed on such as being creative, complex, iterative, holistic, and consistent. It is also shown that all types of design process interaction (process-process, process-people, and process-organization interaction) should be considered in developing process model.

Process models should also be developed according to technology and market needs. And to assure a flexible process model, all the analyzed references agreed on the importance of developing customizable process model that fits different needs and priorities

## Design Process Model Types

Many classification schemes have been developed to describe the different types of design process models. The following table analyses classification schemes which are most relevant to the practical applications which are: stage vs. activity-based, problem vs. solution-oriented and abstract vs. analytical vs. procedural approaches.

Table 2: Comparative analysis of design process models classification schemes  
Adapted from (Wynn, 2005)

	Stage vs Activity-based			Solution vs Problem oriented			Abstract vs Procedural vs Analytical		
	Stage-based	Activity-based		Solution oriented	Problem oriented		Abstract	Procedural	Analytical
<b>Elements</b>	Stages	Activities		Initial solution	Problem sub-elements		Abstracted activities	Stages	Specific activities
<b>Form</b>	Linear, Orthogonal	Cyclical, Rework-intensive		Bottom-up, Cyclic	Top-down, Linear		Cyclical, Rework-undetailed	Linear, Focus on 1 aspect	Cyclical, Rework-intensive
<b>Flow</b>									
<b>Feedback</b>	Only feedback loops between stages	Within each activity		Within each initial solution	Only feedback loops between Problem sub-elements		Within each abstracted activity	Only feedback loops between stages	Within each specific activity
<b>Field</b>	Scientific problems	Design problems		Design problems	Scientific problems		Main design problems	Specific design problems	Specific design problems
<b>Relation to other types</b>									

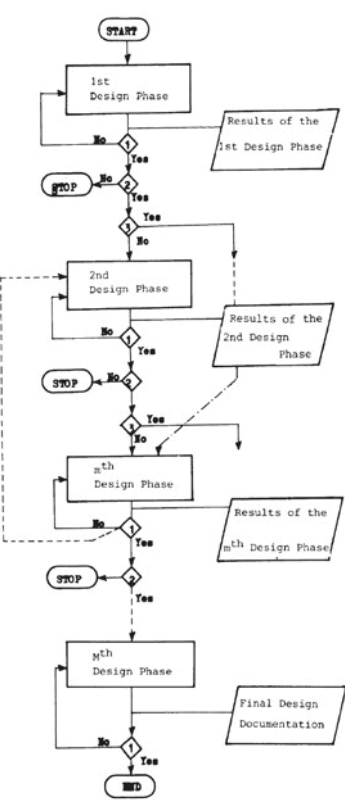
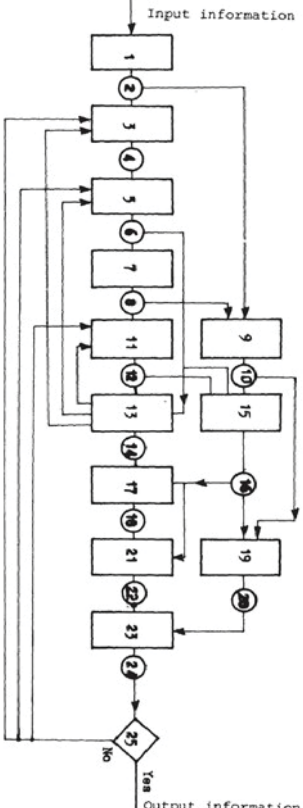
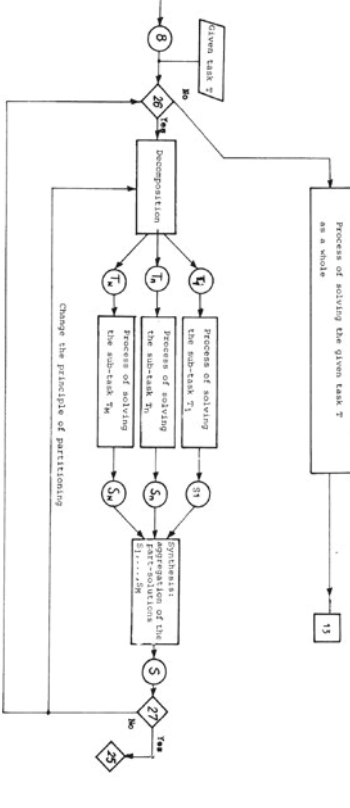
## Design Process Model Structures

The need for setting a structure for design processes emerges from the need for facilitating its complexity. Design process comprises various activities from different disciplines. Each activity has its own method and specialist to deal with. In addition, the sequence of the different activities should be arranged so as to complete the forgoing activity before the following activity is started.

For these reasons, several approaches have been proposed through the literature to structure the design process. Tarnowski W. (Tarnowski, 1986) proposed a comprehensive approach which introduces three types of design process structure as follows:

Table 3: Design Process Model Structures

Adapted from (Tarnowski, 1986)

	Macro-structure	Micro-structure	Decomposition
<b>Scope</b>	Whole design process	One Stage	Whole design process
<b>Elements</b>	Sequential phases	Iterative activities	Sub-activities (Tasks)
<b>Flow</b>	Linear	Cyclical	Linear
<b>Example</b>	 <p>Figure 1: General Scheme for the macro-structure of a design process</p>	 <p>Figure 2: The Micro-structure of the Design Process</p>	 <p>Figure 3: Decomposition in design. T-given task, Tn - part tasks, Sn - their solutions</p>

## Design Process Model Examples

There is a wide number of already existing process models across different disciplines such as: mechanical engineering, industrial design, systems engineering, architecture/building design, software design, service engineering, mechatronics, product-service systems (PSS)-design and models which claim to be applicable independent from a specific discipline (transdisciplinary approaches).

Different analysis and comparative studies of process models across disciplines can be found in literature, however, there is no comprehensive analysis of process models related specifically to architectural design.

The following part introduces four examples of design process models to be analysed to have closer idea of the developed design process models. The examples were selected based on the following criteria:

- Design process model which have been developed specially for building design  
(Architecture and civil engineering)
- Design process model which are widely accepted and used worldwide

The selected examples which fulfill the mentioned criteria are:

1. Royal Institute of British Architects (RIBA) Plan of Work 2013

First developed in 1963, UK, to provide a local and international definitive model for the building design and construction process.

2. The Generic Design and Construction Process Protocol (GDCPP)

Developed in 1998 by the University of Salford, UK, to provide an improved co-ordination between the different parties of construction industry and adopting a 'Process view'. (Rachel Cooper, 2011)

3. American National Standard Institute (ANSI) Consensus Standard Guide 2.0 for Design and Construction of Sustainable Buildings and Communities

Developed in 2007 by the American National Standard Institute to serve as a consensus standard guide and common reference that will support the building industry. ANSI 2.0 has also been incorporated in Leadership in Energy and Environmental Design (LEED) in 2012 to provide evaluation tool which assess a project team's integration and use of this Integrative Process

4. The American Institute of Architects (AIA) Integrated Project Delivery Guide

Developed in 2007 by the collaboration between The American Institute of Architects (AIA) National and AIA California Council. The guide aims to provide information and guidance on principles and techniques of integrated project delivery (IPD) and explains how to utilize IPD methodologies in designing and constructing projects. A collaborative effort.

A comparative analysis of the selected process models is introduced in table 4 to define similarities and differences among them. The comparison shows that most of the analysed models are stage-based models except for ANSI 2.0 which combines stage-based and activity-based types. Accordingly, most of them are linear in form and follow a top-down flow from one stage to another. In addition, each design process model has developed its own group of stages. Some stages are similar in the content but different in their titles, and others are remarkably different. Similar stages are also highlighted in the comparison to further understand the common stages considered in each process model.

Table 4: Comparative analysis of Design Process Models Examples  
Adapted from (RIBA,2013),(Rachel Cooper,2011),(ANSI,2012),(AIA,2007)

	RIBA			GDCPP			ANSI 2.0			AIA-IDP		
Year	1963			1998			2007			2007		
Latest Version	2013			1998			2012			2007		
Application Field	Building Design and Construction			Building Design and Construction			Sustainable Architecture Practices			Building Design and Construction		
Type	<ul style="list-style-type: none"> <li>• Stage-based</li> <li>• Problem-oriented</li> <li>• Procedural</li> </ul>			<ul style="list-style-type: none"> <li>• Stage-based</li> <li>• Problem-oriented</li> <li>• Procedural</li> </ul>			<ul style="list-style-type: none"> <li>• Combined Stage &amp; Activity-based</li> <li>• Combined Problem &amp; Solution-oriented</li> <li>• Procedural</li> </ul>			<ul style="list-style-type: none"> <li>• Stage-based</li> <li>• Problem-oriented</li> <li>• Procedural</li> </ul>		
Form	Top-down linear			Top-down linear			Top-down linear & cyclical			Top-down linear		
Flow	Stages	1 2 . . n	↓	Stages	1 2 . . n	↓	Stages & Activities	1 2 . . n	↻	Stages	1 2 . . n	↓
Feedback	Feedback loops between stages			Feedback loops between stages			Intensive Feedback within each activity & between stages			Feedback loops between stages		
Stages	<ul style="list-style-type: none"> <li>• Strategic Definition</li> <li>• Preparation &amp; Brief</li> <li>• Concept Design</li> <li>• Developed Design</li> <li>• Technical Design</li> <li>• Construction</li> <li>• Closeout</li> <li>• In Use</li> </ul>			<ul style="list-style-type: none"> <li>• Demonstrating the Need</li> <li>• Conception of Need</li> <li>• Outline Feasibility</li> <li>• Substantive Feasibility Study</li> <li>• Outline Conceptual Design</li> <li>• Full Conceptual Design</li> <li>• Co-ordinated Design, Procurement &amp; Full Financial Authority</li> <li>• Production Management</li> <li>• Construction, Operation &amp; Maintenance</li> </ul>			<ul style="list-style-type: none"> <li>• Preparation</li> <li>• Evaluation</li> <li>• Conceptual Design</li> <li>• Schematic Design</li> <li>• Design Development</li> <li>• Construction Documents</li> <li>• Bidding and Construction</li> </ul>			<ul style="list-style-type: none"> <li>• Conceptualization</li> <li>• Criteria Design</li> <li>• Detailed Design</li> <li>• Implementation Documents</li> <li>• Agency Review</li> <li>• Buyout</li> <li>• Construction</li> <li>• Closeout</li> </ul>		

The analysis also shows that there are number of stages that are commonly implemented in the four analyzed process models-however with different terminologies- such as: demonstrating the need, conception of need, conceptual design, developed design, construction documents, construction, and closeout.

On the other hand, some stages are exclusively addressed in one process model such as outline feasibility, substantive feasibility (addressed in GDCPP).

It should be noted that although the 2 feasibility stages only addressed in GDCPP, this does not mean that the other process models did not consider them. As they are implied under other stages or within each stage.

AIA-IDP also addressed one exclusive stage (agency review) which ensure an integrated and co-ordinated design by using Building Information Modeling (BIM) software before construction activities start.

Closeout stage is addressed in all analyzed model except for ANSI 2.0, while operation and maintenance of the building is considered in all the four models except AIA-IDP. Table 5 sums up the different stages of the analyzed models and categorizes them into three types as follows:




-  • Clearly stated and implemented stages
-  • Implied under other stages
-  • Not implemented stages

Table 5: Stages of the analyzed process models

AIA-IDP	ANSI2.0	GDCPP	RIBA		Stages
				Demonstrating the Need	0
				Goal Setting	1
				Outline Feasibility	2
				Substantive Feasibility	3
				Conceptual Design	4
				Detailed Design	5
				Design Development	6
				Construction Document	7
				BIM Coordination	8
				Buyout	9
				Construction	10
				Closeout	11
				Operation	12

## Conclusion

This research has provided a comprehensive literature analysis of design process model to define its main characteristics.

Four parameters were examined to define design process model characteristics which are: principles, types, structure, and examples with special focus on process models related to architectural design as shown in figure 4.

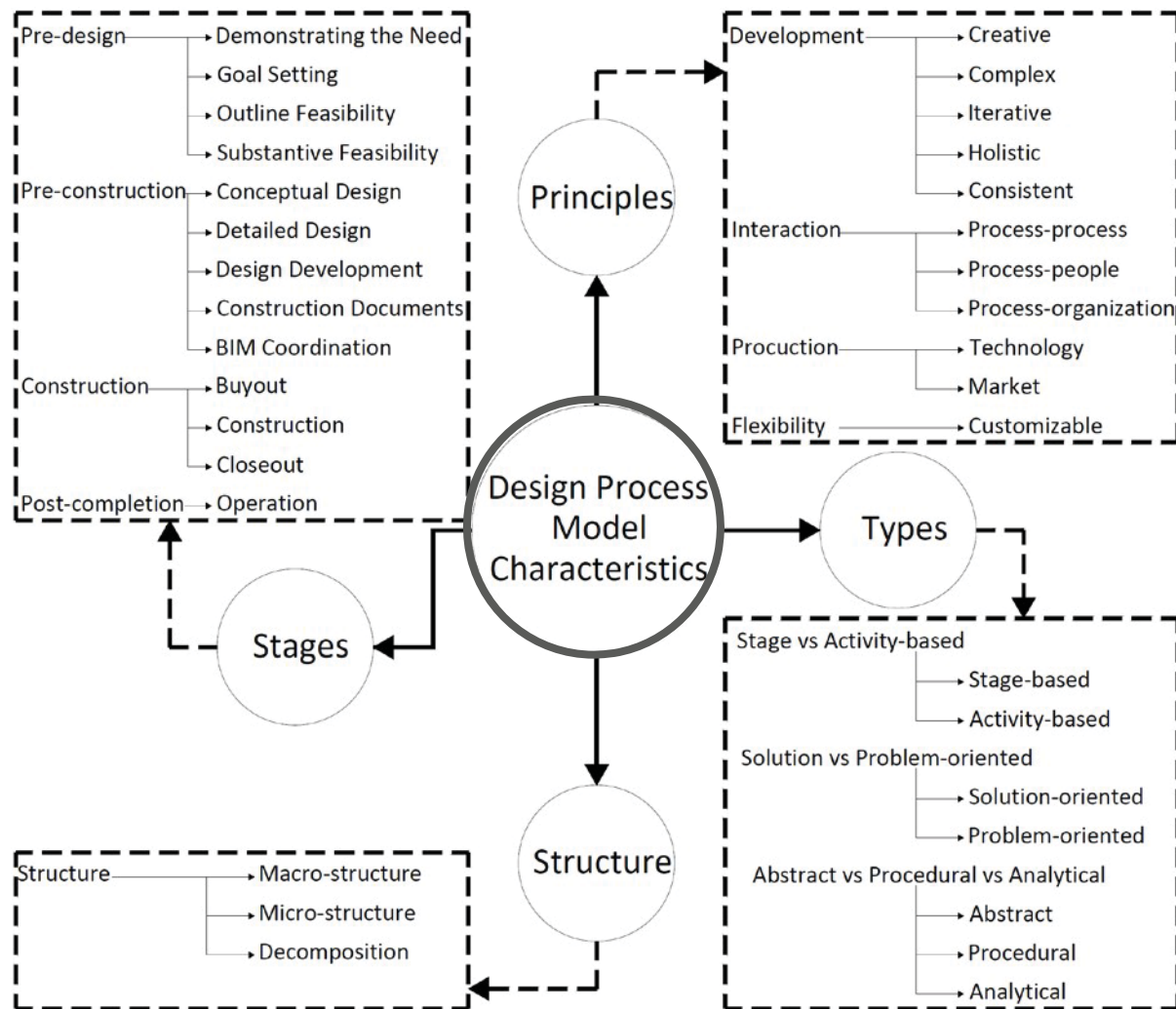


Figure 4: Design Process Model Characteristics

Different principles of design process models were addressed through literature. Commonly agreed on principles were summed up through this study to include: development principles, interaction principles, production principles, and flexibility principles.

In addition, different classification schemes have been used in the previous studies to classify the types of design process models. These different schemes have been comparatively analyzed to determine the main differences of their elements, form, flow, feedback method, field, and relation to each other.

Also different design process model structures have been analyzed so that they can be used properly to develop future models.

Finally, four examples of developed design process models were analyzed to give an idea about the commonly used types, forms, flow, feedback method, and stages included in each of them. Consolidating the fragmented work of design process models is very beneficial for developing more comprehensive integrative design process models



## References

- AIA. (2007). *Integrated Project Delivery Guide*. AIA, AIA CC 2007.
- ANSI. (2012). *Integrative Process (IP): ANSI Consensus Standard Guide 2.0 for Design and Construction of Sustainable Buildings and Communities*. Market Transformation to Sustainability & American National Standards Institute.
- Austin, S. e. (1999). *Analytical Design Planning Technique (ADePT): A Dependency Structure Matrix Tool to Schedule the Building Design Process*. *Construction Management and Economics*, 18, 173 -182.
- Eisenbart, B., Gericke, K., & Blessing, L. (2011). *A framework for comparing design modelling approaches across disciplines*. INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED11 (pp. 1-12). TECHNICAL UNIVERSITY OF DENMARK: Research Gate.
- Gericke, K., & Blessing, L. (2012). *An analysis of design process models across disciplines*. INTERNATIONAL DESIGN CONFERENCE - DESIGN 2012. Dubrovnik - Croatia: ResearchGate.
- Howard, T. J., Culley, S. J., & Dekoninck, E. (2008). Describing the Creative Design Process by the Integration of Engineering Design and Cognitive Psychology Literature. *Design Studies*, 29, 160-180.
- Jones, J. (1984). *Developments in Design Methodology*. Chichester: John Wiley & Sons Ltd.
- Kagioglou, M. C. (1998). *Final Report: Generic Design and Construction Process Protocol*. University of Salford.
- Lawson, B. (1997). *How Designers Think: The Design Process Demystified* (Third edition ed.). Elsevier.
- Maier, A., & Störrle, H. (2011). *WHAT ARE THE CHARACTERISTICS OF ENGINEERING DESIGN PROCESSES?* INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED11.
- Rachel Cooper, M. K. (2011). *The Development of a Generic Design and Construction Process*. University of Salford.
- RIBA. (2013). *RIBA Plan of Work- Overview*. London: RIBA.
- Roozenburg, M. E. (1995). *Product Design: Fundamentals and Methods*. Wiley, Chichester.
- Tarnowski, W. (1986). *THE STRUCTURE OF THE DESIGN PROCESS*. R. Trappl (ed.), *Cybernetics and Systems '86*, 213-220.
- Wallace, K. (1990). *A Systematic Approach to Engineering Design: Design Management*. Oxford: Basil Blackwell Ltd.
- Wynn, D. C. (2005). *Models of designing", Design Process Improvement A review of current practice*. London: Springer.
- Zeisel, J. ( 1984). *Inquiry by Design*. . Cambridge: Cambridge University.

# Learning to improve: An investigation of quality management routines in UK housing development

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**Abstract:** In the UK, housing demand outstrips supply. The number of new homes is increasing but there is a substantial shortfall. In 2016, a parliamentary inquiry investigated the quality and workmanship of new English homes. It found that, as housing output increased, the quality of workmanship, levels of customer satisfaction and dwelling performance fell. This has particular consequences for sustainability targets. This paper explores dwelling performance from a new perspective. Rather than focusing on monitoring new homes in use to assess any performance gap, it investigates how, upstream, a UK volume house builder is learning to eliminate defects through implementing a new quality management routine.

This qualitative study of three regional offices within a large UK volume house builder organisation uses the following methods: document analysis of quality management routines and related standard operating procedure literature; semi-structured interviews with staff; and participant observation of daily work practices across multiple teams.

By developing a new multi-level framework, analysis suggests that there are four simultaneous learning cycles in operation at Individual, Team, Regional and Organizational levels. Social interactions at each level generate new shared learning, drive each learning cycle and link levels together. Time, communication and trust issues create disconnects between the levels, positively and negatively affecting learning cycles around the new quality management routine, with implications for new dwelling performance. This study adds rich qualitative, multi-level, empirical evidence to the current organisational learning literature in an under-researched sector of the construction industry.

**Keywords:** organizational learning, multi-level learning, performance gap, housing, qualitative research

## Introduction

In the UK, housing demand outstrips supply (National Audit Office, 2017). Government targets seek to increase the annual number of new homes built (GB & DCLG, 2017), however few house builders feel this is achievable (Knight Frank, 2014). In addition, a Commission of Inquiry into new housing in England found that, as the speed of new homes built increases, the quality of workmanship, levels of customer satisfaction and dwelling environmental performance decreases (APPG, 2016). This makes the delivery of truly sustainable housing even more difficult. Investigating this challenge from a new upstream angle, is it possible for UK volume house builders to learn how to improve new dwelling performance by improving quality management standards to eliminate defects in the first place?

This paper uses a UK volume house builder organization as a case study to explore multi-level learning cycles in relation to a newly introduced quality management routine. Firstly, learning literature at individual, group and organizational levels are examined to establish how each learning cycle operates, and what their combined relevance is to new dwelling performance. Secondly, the study methodology is presented. Thirdly, a new framework is developed to explore the relationship between individual, group and organizational levels in terms of learning. The conclusion highlights how multiple and simultaneous learning cycles can influence environmental performance in new dwellings.

## **Theoretical Background**

### ***Individual learning and knowledge creation***

Learning is defined as “the process whereby knowledge is created through the transformation of experience” (Kolb, 1984, p. 38). Kolb put forward a conceptual model of individual learning from experience (Vince, 1998). This four-stage cycle describes how, by reflecting on their direct experiences, an individual forms ideas or hypotheses, which they then test by putting them into practice, thus creating new experiences, which can subsequently be reflected on and future ideas refined accordingly (Kolb, 1984). Knowledge is information that has been taken in by an individual and subsequently organised, compared against what they already believe, to establish what that information means to them, and then committed to memory (Nonaka, 1994). However, for organizations to learn, learning has to move from the confines of a single individual experience to include others, through social interaction (Argyris & Schön, 1978; Kim, 1993).

### ***Peer group level learning***

Collective knowledge is created by continuous dialogue between individuals, explicitly expressing and translating internal ideas for others to interpret (Crossan et al., 1999). Over time, as an individual accrues experience, they evolve from a novice to expert based on their participation and membership within their peer group. Therefore, individuals learn “to be” a role rather than simply “do” a role (Lave & Wenger, 1991), implying immediate peer groups should be recognized as a fundamental unit of analysis when studying organizational learning (Brown & Duguid, 2001; Bechky, 2003).

### ***Organizational learning***

As with individuals, organizational experience accrues through repetition, however, organizational learning is more than simply the cumulative learning of its individual members (Crossan et al., 1995; Easterby-Smith et al., 2000; Argote, 2013). Organizations have a *collective and retrievable* historical memory, storing past decisions for future use, developing belief structures and procedural rules, thus differentiating organizational from individual learning (Dosi et al., 2017).

Therefore, organizational learning is a multi-level enterprise, carried out by individuals, peer groups and organizations. A number of seminal learning frameworks have been proposed in the literature that endeavour to explore the reciprocal social processes in action and how they transform learning into actions at, and between, levels (Crossan et al., 1999).

### ***Multi-level learning frameworks***

March and Olsen’s (1975) framework explores the limitations of learning from experience cycles at individual and organizational levels. Their cycle identifies four relationships; firstly, how individual actions influence an organization’s actions which, secondly, influences how the environment responds to that action. Thirdly, the outcome impacts on what an individual believes in relation to that action and, fourthly, the cycle starts again. Each relationship can break down, however, leading to an incomplete learning cycle. This can mean: individual learning no longer influences individual behaviour; environmental outcomes fail to change despite changes to organizational behaviour; organizational actions are no longer influenced by individual learning, or causal connections between the

organization's action and subsequent environmental response are misinterpreted by an individual.

Kim's (1993) framework examines how learning is transferred from an individual to the organisation via their individual mental models (i.e. non-verbal images in the head of an individual in relation to their understanding). At the organizational level, the concept of organizational learning is proposed based on a dialogue between individual and organizational mental models. For learning to move between levels, Kim argues that individuals need to clearly express their mental models to others. Within this enhanced learning framework, additional links can also break, leading to: quick problem solving where nothing is remembered for later use; siloed learning where individuals learn but collectively the organization does not, or standard organizational protocols being side-stepped to quickly achieve a goal that serves the needs of a few, not the organization as a whole.

Finally, Crossan et al. (1999) propose a comprehensive framework comprising individual, group and organizational levels to explore how organizations feed forward new knowledge in relation to what they already know. It suggests "intuiting" at the individual level – the presence of non-verbal subconscious ideas, experiences and thoughts. These individual ideas, experiences and thoughts are "interpreted" to the group level for others to interpret and understand in their own way. "Integrating" then takes place between group and organizational level, where the ideas, experiences and thoughts are boiled down to something everyone in the group understands and agrees on. Finally, these concentrated thoughts are "institutionalized" at an organizational level by using them to develop and implement formal routines and procedures.

Whilst learning literature puts forward a number of multi-level frameworks, there is still a lack of empirical evidence to support them, particularly around how the levels align alongside and connect with each other. More field work is needed, and housing is particularly relevant as it presents a different way to explore learning in relation to environmental performance.

Implementing a quality management routine, i.e. through activities such as quality assurance and quality control, is recognised as one way of addressing the performance gap by improving build quality standards (Zero Carbon Hub, 2014; APPG, 2016). Here, quality management is defined as, "management with regard to quality" (ISO 9000:2015, 2015, cl 3.3.4), and routines are defined as, "repetitive patterns of interdependent organizational actions" (Parmigiani & Howard-Grenville, 2011, p. 414).

## **Case background**

A qualitative case study approach has been taken (Eisenhardt, 1989; Flyvbjerg, 2006; Yin, 2013) to explore multi-level learning cycles in depth over time. Given the focus of this study is on day-to-day practices, the concept of the routine has been used to guide the research design. A routine comprises *ostensive* traits, which relate to an individual's perception of what a routine involves, *performative* characteristics, which relate to the routine's actual performance, and *artefacts*, the associated documentation (Feldman & Pentland, 2003). By triangulating interview content (ostensive views) and guidance documentation (artefacts) with participant observation data (actual performance), it is possible to compare whether the routine guidance has been interpreted as intended by individuals and subsequently carried out as the organizational level envisaged.

### *Case Study Organization overview*

The case study organization is a typical large UK volume house builder with a total workforce of 850 people in regional offices across England. Each Region, under a Managing Director, comprises seven teams: Development; Technical; Commercial; Build; Customer Care; Sales; and, Finance. At an Organizational level, Regions are supported by services, such as Health and Safety, Sustainability, IT and Quality Teams etc. - all based within the Organization's Head Office. Three Regions are being studied; each employing 150 staff.

The organization was selected as it was in the process of implementing substantial amendments to its quality management procedures and was receptive to further studies exploring learning in relation to the roll out. A theoretical sampling approach has been adopted; the Regions have been selected based on their performance in relation to customer satisfaction scores.

#### *New quality management routine*

From interviewing members of staff, it was reported that the Quality Team started implementing a new quality management routine across the organisation in 2014. The routine data comprised three parts: firstly, a Quality Handbook, which set out the construction and finishing standards expected on site. It gave descriptions and photographs of key elements for each construction trade, as to what a Site Manager will accept and what they will not; secondly, a During-Construction Quality Inspection (DCQI) procedure, carried out by the Site Manager, for each new dwelling, at four key stages of the construction process to ensure mistakes are rectified at the correct point in time. This was observed to be a tick-off, comment and sign off, paper-based inspection form which stayed with the plot until handover, where it was filed at each regional office; and lastly, a Site-wide Quality Spot Check (SQSC), carried out by the Quality Team with the relevant site's Regional Site Manager, Build Manager, Technical Manager and Project Architect present. The SQSCs were one-off inspections where a selected number of dwellings at different construction stages were assessed to establish whether the Quality Handbook standards were being met on site. This inspection was followed by a written report for the Regional Build and Technical Teams to action. In terms of the organization's quality management activities, the Quality Handbook focused on quality assurance, whereas the DCQIs and SQSCs concentrated on quality control.

### **Methods**

#### *Data Collection*

Data was gathered between October 2015 and February 2016. Time was spent observing participants across three Regions in the Technical, Commercial, Build and Customer Care Teams. In each Region, at least one development was identified where a SQSC was due to be carried out. Selected individuals involved with those projects were shadowed during the work day for between one and three days. Data comprised documentation, field notes of observations, audio recordings, notes of meetings and meeting hand-outs. Views from staff were captured through 18 semi-structured interviews, 20 audio files of unstructured one-to-one conversations recorded whilst carrying out day-to-day work, and 10 audio files of meetings or day-to-day activities observed. In total, 62 hours and 19 minutes of audio data was captured; 17 hours and 45 minutes being transcribed verbatim, with the remainder written up as notes with salient quotes.

Questions to participants centred around the new quality management routine and their relationship to it, job roles, relationships to other Teams and other Regions, process improvement, feedback and learning, work-related issues being dealt with at that point in

time, quality management routine adherence, as well as how staff achieved their goals in other ways.

Relevant documentation was selected, e.g. the Quality Handbook, SQSC guidance and reports, DCQI guidance and supporting paperwork, and intranet web pages relating to quality management routines. Information was also gathered about the setup of each Region.

#### *Data Analysis*

All data was analysed inductively to identify themed categories related to organisational learning, as well as triangulating findings from the mix of methods (Eisenhardt & Graebner, 2007; Robson, 2013). Interview transcripts, field notes, documentation and audio notes were thematically coded manually using NVivo 11 software from a cross-case perspective (Eisenhardt, 1989) to identify patterns in the data, thus identifying 'first order' concepts, and 'second order' themes (Gioia et al., 2013). Once a number of first order concepts were identified, these were distilled into three emerging second order themes; time, communication and trust.

A new multi-level learning framework was subsequently developed for the case study housing organisation in relation to the new quality management routine. Through an iterative process of moving between the literature and data, this framework was refined and used to illustrate examples of where the learning cycles aligned or operated in isolation, how the levels connected to each other, and resulting implications for new housing performance.

### **Detailed Findings**

#### ***Developing the housing framework***

At this house builder organization, four learning levels of cycles were identified: Individual as the smallest unit of analysis; Teams (a number of Individuals operating under a Team Executive); Regions (a number of Teams operating under a Regional MD), and Organizational (a number of Regions and all support functions operating under a Chief Executive Officer, CEO). Teams also had a relationship with External Organizations (Consultants, e.g. Architects, or Trades, e.g. Bricklayers) who often worked in more than one Region. Figure 1 illustrates the framework developed during this study. The formation is explained next.

At an Individual level, Kolb's (1984) experiential cycle captured the internal processes of trial and error learning seen in this study.

Data analysis revealed that individuals formed part of a Team, where learning was shared between fellow Team members (represented by the dashed Shared Learning circle). Thoughts and experiences were discussed and distilled into Team actions. The house building environment responded to those actions, which the Team observed, discussed again in relation to their shared experience, refined and actioned again; the cycle continued. Teams worked with Individuals from External Organizations. These Individuals contributed their experience to the Team discussions; however, they also carried out their own actions, to which the house building environment responded and they observed in relation to their specific perspective, shaping their future ideas, which may differ from those of the Team.

The Regional learning level was similar to the Team level, however different Teams came together to share their learning and experience. This culminated in actions at Regional



level which the environment responded to. The Region observed and refined their shared learning experience accordingly as the cycle continued.

At an Organizational level, the Regions and support functions came together to discuss strategic actions, form memories, refine old or outdated routines and implement new ones. As before, the environment responded, the Organizational level observed and made changes based on shared observations.

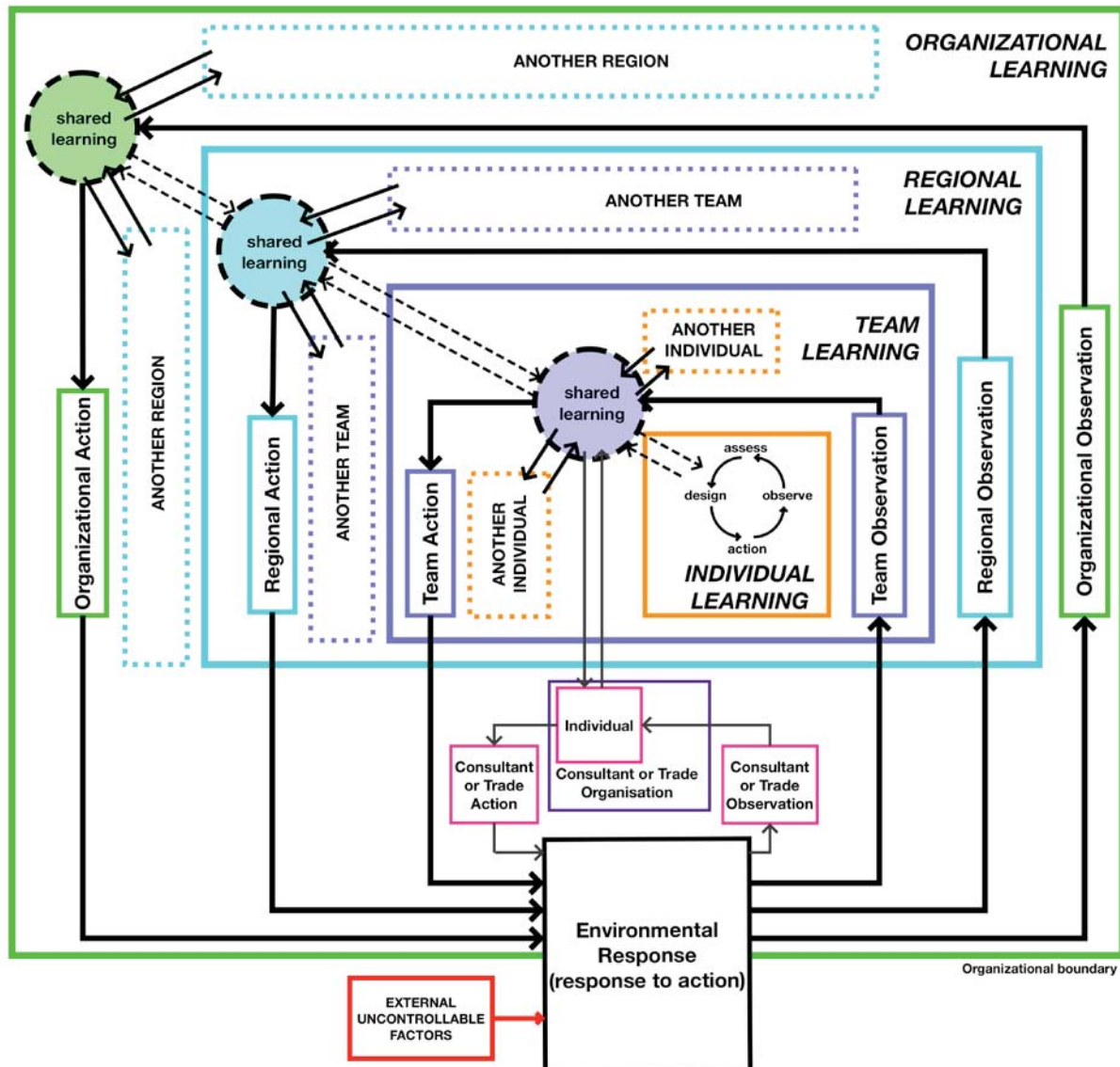


Figure 1. Case study housing organization multi-level learning framework

### Emerging themes

Given the limited word count, an in-depth exploration of the evidence trail goes beyond the scope of this paper. Therefore, three themes that emerged from the data which impact on dwelling performance have been selected for further discussion.

#### Time

Housebuilding is a long process; for this housing organization, most developments take at least year to go from brief to drawing board and another year to build on site. It was

observed that whilst parts of the quality management routine were carried out on numerous dwellings at once (i.e. the DCQI), they took place in parallel, not consecutively. And, as latent defects can emerge years after post-completion (Taggart et al., 2014), whole feedback cycles encompassing briefing, design and construction can consequently take years. Therefore, if there is a substantial delay between action and observation, causal ambiguity may lead to “superstitious learning” (March & Olsen, 1975; Levitt & March, 1988) or a positive bias towards how an action is recalled (Tversky & Kahneman, 1974). How events are recorded at the time and drawn on in future are therefore crucial to improving quality management routines and building Organizational memory.

In contrast, the speed at which Individual and Team cycles were observed to operate was far faster. By adapting the quality management routine locally to suit current circumstances, Teams were able to achieve short-term, day-to-day targets by being quick and pragmatic; however, this could be deemed risky given the long-term impacts of their decisions on dwelling performance were uncertain (Bordass, 2003; Zero Carbon Hub, 2014).

This was observed during a Site-wide Quality Spot Check (SQSC) at Site A in Region 1. The Site Manager, Build Manager, Technical Manager and Architect were asked by the Quality Team Executive to reflect on the construction process to date; in particular the decision to change the roof build-up mid-construction to help meet programme deadlines. Multiple Teams at Region 1 had conversed about options but the standard Organisational routine to assess a change request was not pursued. This led to problems with material availability, revised design work errors, insulation being omitted in parts and extra sub-contractor co-ordination. These factors were not considered when the action to change the roof build-up was taken but ultimately will affect future dwelling performance.

In terms of learning, there was a serious feedback disconnect between the environmental response and Shared Learning circles at local levels. i.e. without the SQSC it was uncertain whether any considered observation would have taken place to inform future long-term Individual or Team actions, or been transferred to higher levels to improve Organizational memory. This was further reinforced by comments from interviewees across the Organization, who felt they had limited time to reflect on the longer-term impacts of their actions between projects.

### *Communication*

Implementing a quality management routine required each level to have an understanding of what the routine aimed to achieve and how to carry it out. Interpretation within the Shared Learning circles played a key role in how the routine was communicated and understood across levels, as Individuals were influenced by the interpretations of others, particularly those they trusted (March & Olsen, 1975). Whilst guidance on the routine was given, several approaches fell within the guideline's parameters, depending on each individual's comprehension and point of view (Feldman & Pentland, 2003). This gave scope for variations in the routine to occur. As the levels moved out from the centre, more Individuals were involved in the learning cycles but not directly involved in the sharing learning discussions. Instead they relied on second hand accounts of discussions from others.

This was observed in relation to how the QH was implemented in Region 1. Informal verbal feedback from Site Teams to the Commercial Team in the regional office highlighted the difficulties on site of installing a specific type of insulation in a certain part of a dwelling. Despite the QH covering insulation installation, it did not address the areas Site Teams found problematic. Whilst not party to the initial conversations, a member of the Commercial Team (Participant A), after overhearing issues from colleagues, looked to

alleviate the problem on future sites by using their initiative and changing the insulation specified in that area. This meant deviating from the Organization's standard specification to solve a local problem. By contrast, in Region 3, the same problem was highlighted during a SQSC. The Site Team was instructed by the Quality Manager to use a different type of insulation but one that was in line with the Organization's standard specification. This highlighted that whilst both Regions have had to interpret the QH, one had done it in line with the Organization's standards, and the other had not. The divergence of practices across Region 1 increased the risk of inconsistency from the Organization's perspective, as to what sustainable housing performance targets were being aimed for, and met, on site.

### *Trust*

In this case study, a formal Organizational notion of trust seemed to centre on expectations from senior Regional Management that Individuals had the ability to build new dwellings in line with the Organization's formal procedures. At the same time, an underlying informal notion of trust was also present and observed; expectations that Individuals could build new dwellings on time. i.e., in terms of priorities, the procedural journey was potentially irrelevant; the rules could change to suit the circumstances given good justification. Here, trust is defined as "the willingness of a party to be vulnerable to the actions of another party based on the expectation that the other will perform a particular action important to the trustor, irrespective of the ability to monitor or control that other part" (Mayer et al., 1995, p. 712). Therefore, whilst a formal view of trust was exhibited by Senior Management, which centred around the performance of the action, Individual behaviour and subsequent actions were influenced by the informal tones implied by the lack of monitoring against a background of expectation (Vince & Saleem, 2004). Therefore, what was said at one level was not done at another level, which may or may not have been admitted.

This informal undercurrent of trust in relation to expectation was observed driving Individual and Team behaviour (Participants D and E) in Region 2 when instructed by a senior Regional Management member (Participant B) to follow an Organizational final sign-off routine for new dwellings. The routine had already been changed from the standard Organizational procedure due to a shift in priorities and circumstances in that Region. The routine devolved again at the Team level to allow deadlines to be met, with both Participant D and E expressing between themselves the expectation from above was to complete and hand over the dwellings rather than explicitly follow process.

This example highlighted a disconnect between the formal Organizational procedural rhetoric, and informal attitude about getting the job done. It ran the risk of any local practices or changes that emerge being kept at an Individual or Team level, as they explicitly went against Senior Management instruction. The fear of being reprimanded kept communication to a minimum between those trusted (Liu et al., 2017). Also, the learning associated with this behaviour was not driven by the Organization's formal stance but the informal one (Vince & Saleem, 2004).

## **Discussion**

Examining the examples above in tandem with the learning framework, this section starts to explore how the multi-level learning cycles work in operation around the new quality management routine, introduced by the case study house builder organisation.

For learning to occur at each level, all learning cycles have to revolve in a synchronised anticlockwise direction, driven by their specific Shared Learning circle acting as a cog. For

learning to move between levels, a two-way relationship is needed to link Shared Learning circles. A metaphor to describe the motion would be to envisage each Shared Learning level circle “cog” joined together by a roller chain like a bicycle. The cogs turn together, aligning or “coupling” the learning cycles. In contrast, the chain can “fall off” between Shared Learning circles meaning the learning cycles “decouple” at that level and revolve independently from the others (Breslin & Wood, 2016).

There are advantages and disadvantages to this coupling and decoupling, particularly in housing development. Decoupling allows for a situation specific solution to be developed and actioned quickly (i.e. a local practice emerging), providing a bottom-up source of innovation. However, it can be risky from an Organizational perspective if no formal quality management routines are being followed and widespread uncontrolled construction activities are being conducted to varying standards. Recoupling of learning cycles means the Organization’s construction activities are re-aligned and learning is uniform across all levels again; however, changes implemented from the Organizational level down can often happen too slowly to meet the need at Team or Individual levels, whilst creating a degree of inertia.

Instances of coupling, decoupling and recoupling were observed during the study. For the new quality management routine to be adopted across the Organization, as it moved from the Organizational level to the Individual level, it was adapted to meet current needs and circumstances. Rather than it being carried out in exactly the same way at every level, *it changed*; moving away from its intended formal format and becoming a practice better suited to the immediate local conditions. Here the Shared Learning circles *decoupled* to allow new local practices to occur alongside the Organization’s formal quality management routine and learning cycles to run independently. This was problematic as it meant many inconsistent versions of the quality management routine were being conducted simultaneously across Regional, Team and Individual levels.

In the instance above, where the roof build-up was changed, the Regional and Team learning cycles decoupled from the Organizational level cycle to pursue a different way of instructing variations, which circumvented the Organization’s formal routine. This local change was perceived at Regional, Team and Individual levels to be beneficial, as it pragmatically addressed the current problem in the short-term. The longer-term, reflection-based perspective offered by the Organization’s standard procedure, arguably informed by the Organization’s memory and past experience to prevent short-term, knee jerk reaction decisions from being taken, was ignored. In an attempt to recouple all learning cycles (i.e. put the chain “back on” between Shared Learning circles), the Organization’s formal stance was reiterated and associated procedure reinstated by the Quality Team Executive during the SQSC. This was done by discussing how following the Organization’s formal change request routine may have resulted in a better, less unpredictable outcome. It would have taken more time to pursue, as additional Teams needed consulting but given a longer-term appraisal of the situation. Also, adding an Organizational level dimension to this SQSC discussion allowed time for the Individual and Team levels to observe and assess the implications of their actions.

Similarly, at an Individual and Team level, the Shared Learning circles and associated learning cycles decoupled from each other in both Regions 1 and 3 when decisions about insulation choice in difficult to reach locations were being reassessed for future projects. However, at Region 3, a discussion at Organizational level during an SQSC resulted in the learning cycles recoupling when the problem could be solved by using insulation in line with

the Organization's standard specification. Therefore, the SQSC provided an opportunity to cross the Shared Learning circles and connect the Organizational level to those below it, transferring the learning whilst gaining local feedback. At Region 1, the learning cycles remained decoupled, as the local practice of using a non-standard insulation product stayed in place. The lack of feedback between the Regional and Organizational levels resulted in learning remaining in a local silo. This decoupling also meant that learning at Regional, Team and Individual levels in Region 1 was different to Region 3, resulting in a discrepancy in thermal performance between future new dwellings.

Where informal and formal ideas of trust worked in conflict with each other, all Shared Learning circles decoupled, spinning freely, and learning cycles revolved in isolation. These actions enabled the task at hand to be completed expediently but afforded little in-depth thought or reflection. Here, no recoupling of learning cycles was observed. This meant Individuals had no learning in relation to the new quality management routine, aimed at improving housing performance, instead they learnt it was acceptable to change the rules, behave accordingly and justify their reasoning later; not a positive learning outcome from an Organizational perspective, or in terms of addressing the housing performance gap.

## **Conclusion**

This study tries to look at new housing performance from an upstream perspective. Rather than focusing on monitoring new dwellings in use, to assess any performance gap, it investigates how volume house builders are learning to eliminate defects through implementing a new quality management routine. By developing a multi-level framework to study various simultaneous learning cycles, it adds a means to examine the social aspects behind learning and how it transcends levels.

The findings here only relate to a four-month period shortly after the routine had first been introduced, and present an 'early days' snapshot rather than an in depth look at sustainable housing performance over time, but they clearly indicate some key issues. Further research is required to understand the full context of a complete housing project in relation to the new framework proposed, as the introduction of any new routine takes time to embed given the long nature of procurement in housing.

Findings so far suggest that learning generated through social interactions at Individual, Team, Regional and Organizational level drive their specific level's learning cycle, as well as linking the levels together. When linked together, or "coupled", learning is uniform across the levels meaning the routine is being implemented consistently; all cycles are aligned. When learning levels are not linked or "decoupled", new practices emerge at each level to suit the local conditions; variations of the formal routine. Ad hoc or selective quality management routine adoption following gradual implementation leads to ambiguity about which quality standards are actually being met on site. The flip side is that these new local practices, or examples of bottom-up innovation could be captured, fed back to the Organizational level and subsequently exploited.

The compounded impact of both learning cycle and construction feedback time lags affects sustainable housing performance. Unless actions result in major defects, often the effect of minor performance-related decisions go unchecked, as over time they get forgotten or the number of influencing factors becomes so large it is impossible to establish any meaningful causal relationship.

Interpretation plays a significant role across the house building industry, with misinterpretation being common place. This study highlights how guidance can be



understood in a variety of ways within a single organization that shares goals and values. How new local practices develop depend on how the quality management routine is communicated at an Organizational level and subsequently interpreted at each level. As interpretation varies between Individuals, Teams and Regions, divergence could be wide ranging. Without any checks, this divergence could increase over time, opening the Organization up to additional risk through substantial variations in target and achieved dwelling performance standards.

Dwelling performance-related consequences arise during construction when Individual and Team behaviour is driven by a conflict between formal and informal perceptions of trust from senior Regional Management. Individual and Team actions are changed to suit informal priorities. Organizational routines are not followed but changed at every level, endorsed by a belief that actions can be justified later. The implications are that these amended actions and practices are concealed as they often go against direct instructions, hindering any transparency between levels, and the associated learning is negative with a focus on bending the rules, not meeting set Organizational standards. The knock-on effect for dwelling performance is that, what is said at one level is unknowingly not done at another. And often as Individuals at different levels cannot be everywhere at once, it is not always possible to check items before they are covered up during construction.

Looking at housing from a learning perspective, rather than an in-use performance angle, is vital to help meet the challenge of increasing the number and rate of houses built, whilst improving new dwelling sustainability.

## References

- All Party Parliamentary Group for Excellence in the Built Environment (2016) *More Homes, Fewer Complaints. Report from the Commission of Inquiry into the Quality and Workmanship of New Housing in England*, Available from: <<https://kj06q2hv7031ix2143c36tpx-wpengine.netdna-ssl.com/wp-content/uploads/2016/07/APPG-Final-Report-More-Homes-fewer-complaints.pdf>> [Accessed: 1 September 2017]
- Argote, L. (2013) Chapter 2 - Organization Learning: A Theoretical Framework, *In: Organizational Learning*, Boston, MA: Springer US, pp.31–56
- Argyris, C. & Schön, D.A. (1978) *Organizational Learning*, Reading, Mass: Addison-Wesley Pub. Co
- Bechky, B.A. (2003) Sharing Meaning Across Occupational Communities: The Transformation of Understanding on a Production Floor, *Organization Science* 14 (3): 312–330
- Bordass, W. (2003) *Partners in Innovation: A Feedback System for Construction Clients and the Industry. An Initial Guide to Feedback*, London: William Bordass Associates
- Breslin, D. & Wood, G. (2016) Rule Breaking in Social Care: Hierarchy, Contentiousness and Informal Rules, *Work, employment and society* 30 (5): 750–765
- Brown, J.S. & Duguid, P. (2001) Knowledge and Organization: A Social-Practice Perspective, *Organization Science* 12 (2): 198–213
- Crossan, M.M., Lane, H.W. & White, R.E. (1999) An Organizational Learning Framework: From Intuition to Institution, *The Academy of Management Review* 24 (3): 522
- Crossan, M.M., Lane, H.W., White, R.E. & Djurfeldt, L. (1995) Organizational Learning: Dimensions for a Theory, *The International Journal of Organizational Analysis* 3 (4): 337–360
- Dosi, G., Marengo, L., Paraskevopoulou, E. & Valente, M. (2017) A Model of Cognitive and Operational Memory of Organizations in Changing Worlds, *Cambridge Journal of Economics* 41 (3): 775–806
- Easterby-Smith, M., Crossan, M. & Nicolini, D. (2000) Organizational Learning: Debates Past, Present And Future, *Journal of Management Studies* 37 (6): 783–796
- Eisenhardt, K.M. (1989) Building Theories from Case Study Research, *Academy of Management Review* 14 (4): 532–550
- Eisenhardt, K.M. & Graebner, M.E. (2007) Theory Building from Cases: Opportunities and Challenges, *Academy of Management Journal* 50 (1): 25–32



- Feldman, M.S. & Pentland, B.T. (2003) Reconceptualizing Organizational Routines as a Source of Flexibility and Change, *Administrative Science Quarterly* 48 (1): 94–118
- Flyvbjerg, B. (2006) Five Misunderstandings About Case-Study Research, *Qualitative Inquiry* 12 (2): 219–245
- Gioia, D.A., Corley, K.G. & Hamilton, A.L. (2013) Seeking Qualitative Rigor in Inductive Research: Notes on the Gioia Methodology, *Organizational Research Methods* 16 (1): 15–31
- Great Britain & Department for Communities and Local Government (2017) *Fixing Our Broken Housing Market*, Available from: <[https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/590464/Fixing\\_our\\_broken\\_housing\\_market\\_-\\_print\\_ready\\_version.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/590464/Fixing_our_broken_housing_market_-_print_ready_version.pdf)> [Accessed: 9 September 2017]
- ISO 9000:2015 (2015) ISO 9000:2015(en), Quality Management Systems — Fundamentals and Vocabulary, Available from: <<https://www.iso.org/obp/ui/#iso:std:iso:9000:ed-4:v1:en:term:3.3.6>> [Accessed: 13 November 2017]
- Kim, D.H. (1993) The Link between Individual and Organizational Learning, *Sloan Management Review* 35 (1): 37–50
- Knight Frank (2014) *Building Momentum: House Building Report 2014*, Available from: <<http://content.knightfrank.com/research/297/documents/en/2014-2075.pdf>> [Accessed: 3 September 2015]
- Kolb, D.A. (1984) *Experiential Learning: Experience as the Source of Learning and Development*, Englewood Cliffs, N.J: Prentice-Hall
- Lave, J. & Wenger, E. (1991) *Situated Learning: Legitimate Peripheral Participation*, Cambridge [England]; New York: Cambridge University Press
- Levitt, B. & March, J.G. (1988) Organizational Learning, *Annual Review of Sociology* 14 (1): 319–338
- Liu, W., Song, Z., Li, X. & Liao, Z. (2017) Why and When Leaders' Affective States Influence Employee Upward Voice, *Academy of Management Journal* 60 (1): 238–263
- March, J.G. & Olsen, J.P. (1975) The Uncertainty of the Past: Organizational Learning Under Ambiguity, *European Journal of Political Research* 3 (2): 147–171
- Mayer, R.C., Davis, J.H. & Schoorman, F.D. (1995) An Integrative Model of Organizational Trust, *The Academy of Management Review* 20 (3): 709–734
- National Audit Office (2017) *Department for Communities and Local Government. Housing in England: Overview*, Available from: <<https://www.nao.org.uk/wp-content/uploads/2017/01/Housing-in-England-overview.pdf>> [Accessed: 9 January 2017]
- Nonaka, I. (1994) A Dynamic Theory of Organizational Knowledge Creation, *Organization Science* 5 (1): 14–37
- Parmigiani, A. & Howard-Grenville, J. (2011) Routines Revisited: Exploring the Capabilities and Practice Perspectives, *The Academy of Management Annals* 5 (1): 413–453
- Robson, C. (2013) *Real World Research*, Wiley Available from: <<http://www.wiley.com/WileyCDA/WileyTitle/productCd-1118531507.html>> [Accessed: 20 November 2017]
- Taggart, M., Koskela, L. & Rooke, J. (2014) The Role of the Supply Chain in the Elimination and Reduction of Construction Rework and Defects: An Action Research Approach, *Construction Management and Economics* 32 (7–8): 829–842
- Tversky, A. & Kahneman, D. (1974) Judgment under Uncertainty: Heuristics and Biases, *Science* 185 (4157): 1124–1131
- Vince, R. (1998) Behind and Beyond Kolb's Learning Cycle, *Journal of Management Education* 22 (3): 304–319
- Vince, R. & Saleem, T. (2004) The Impact of Caution and Blame on Organizational Learning, *Management Learning* 35 (2): 133–154
- Yin, R.K. (2013) *Case Study Research: Design and Methods*, Los Angeles: SAGE
- Zero Carbon Hub (2014) *Closing the Gap between Design and as-Built Performance. End of Term Report*, Available from: <[http://www.zerocarbonhub.org/sites/default/files/resources/reports/Design\\_vs\\_As\\_Built\\_Performance\\_Gap\\_End\\_of\\_Term\\_Report\\_0.pdf](http://www.zerocarbonhub.org/sites/default/files/resources/reports/Design_vs_As_Built_Performance_Gap_End_of_Term_Report_0.pdf)> [Accessed: 6 May 2015]

# Framework for capacity based sustainable design & development; towards resilient communities

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**Abstract:** The most fundamental struggle for realizing a sustainable built environment still lies in the use of non-renewable resources in its articulation. Although effort has been taken to increase the use of sustainable materials (bio based, C2C, etc.) the vast majority of the building sector still relies heavily on steel and concrete. This article debates that the most fundamental contributors to sustainable development are the evaluation and incorporation of inhabitant capacities. Evaluating the proximity of available natural materials, inhabitant skills and tools could play a fundamental role in creating (social) sustainable societies and environments. However, inhabitant capacity models insufficiently cover the various capacities into one model (both inhabitant and community). Therefore, this article describes: a framework for evaluating inhabitant capacities; how to map available resource capacities; how these capacities can be incorporated into sustainable housing development and planning. The framework was developed as a part of a support tool, which helps designers and engineers to evaluate inhabitant capacities. To describe the framework and support tool a rural Sub-Saharan community is used- their capacities are relatively less complex compared to a 'western' or urban context. Moreover the articulated built environment is relatively uncomplicated. The article concludes that the framework shows great potential in reducing the use of unsustainable materials. Moreover, that it could enable social sustainability by creating self-reliant and resilient communities.

**Keywords:** inhabitant capacities; resource capacities; social sustainability; resilient communities; self-reliance

## Introduction

Although sustainable design has been debated for an extensive time (Page, 2014), its interpretations are sometimes contradicting and confusing (Lélé, 1991). In the literal sense sustainability describes the ability to which something can be maintained at a certain level or rate, over a certain amount of time. From an environmental point of view, sustainability describes goods and services that do not use materials that cannot be replaced or that in any way damage the environment (Cambridge Dictionary, 2017). Its definition is thus clear, unlike the interpretation of damage (depleting resources, carbon emissions, social inequality, etc.).

Sustainable design is often less strict and clear. In most cases it refers to reducing environmental impact through design (Vargas Hernandez, Okudan Kremer, Schmidt, & Herrera, 2012), which implies that in the building industry the definition seems less strict. Although sustainable design has good intent: using local, natural and renewable resources, ensuring future generations can sustain a 'good' quality of life (Felce & Perry, 1995), talks about reducing bad impact instead of using sustainable solutions as departure point. With the building industry still as one of the heaviest polluting industries (Bribián, Capilla, & Usón, 2011) and main contributor to carbon emissions and resource depletion (steel, concrete, etc.), this might not be that surprising.

The 'formal' built environment might have a bad reputation, the 'informal' built environment shows quite the opposite. The ecological footprint (Wackernagel & Rees, 1998) of rural inhabitants in Third World countries is many times smaller than urban inhabitants in First World countries (Van Vuuren & Bouwman, 2005). The informal building production contributes to an extensive part of the entire global housing production (UN-Habitat, 2015).

However, with a rapid urbanization especially of developing countries these inhabitants will likely increase their ecological footprint. Therefore, sustainable design and development might emphasize more on preventing impoverished communities following the unsustainable example, offering a sustainable design and development alternative for ‘developing’ communities in the Global South.

In the Global South most rural inhabitants build houses primarily by themselves based on available materials, tools and skills. All contributors to self-building practices in this article are called: *inhabitant self-building capacities*<sup>1</sup>. This self-build practice is often supported by materials, tools and skills offered by relatives, friends or close community members, which in this article is called: *proximal self-building capacities*. Furthermore the gap in inhabitant self-build capacities and proximal capacities is often filled by capacities available in the periphery of their community, which in this article are called: *peripheral self-building capacities*.

This way of building is sustainable in terms of the ecological footprint of used materials, little transport being involved in a process (materials, labourers, etc.). What is more the building production generates an extremely high socially sustainable (resilient) development of the built environment. However, the vast majority of the informal built environment (vernacular, slums, camps, etc.) has a low Quality of Life (Felce & Perry, 1995) compared to the formal built environment. Indicating that even though the articulated built environment is highly sustainable in terms of design and development, it has not been able to substantially improve the inhabitants Quality of Life (QoL). It does show a potentially crucial model, framework and methodology for the articulation of a sustainable built environment.

This article argues that one of the most important factors for the success of the sustainable informal built environment can be explained by “self-building capacities”. This means that all capacities a rural inhabitant needs to build a dwelling are available in their direct surrounding. Although inhabitant self-building capacities could be highly valuable for sustainable design and development, a framework to assess inhabitant self-building capacities does not yet exist. Therefore, the article firstly articulates a framework for inhabitant self-building capacity evaluation. To enable designers to use such framework in situ, a design support is described consecutively.

The developed framework and design support use a mixed method approach, combining: mapping, context analysis, interview and observation methods. Secondly, the framework and design tool describe how to assess capacities (inhabitant, proximal and peripheral) weigh them against alternative building solutions. Lastly, it allows planning of building activities according to all the capacities (inhabitant, proximal and peripheral), combining the capacities of the families with those of their neighbours, family and other community members. The framework is an essential part of the sustainable design support tool formulated within a larger PhD research. This article uses a rural Sub-Saharan family and its community to explain how the framework can be used. Rural Sub-Saharan community’s capacities are relatively less complicated compared to a ‘western’ urban context and therefore easier to analyse.

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<sup>1</sup> Inhabitant capacities: all factors that enable the inhabitants to produce a dwelling by themselves, which include: tools, resources, knowledge, skills and income

## Methodology

This investigation seeks to determine if a specific treatment influences inhabitant self-reliance towards their built environment and is therefore an experimental research (Creswell, 2013). Within this article the framework of the support as a part of this ‘treatment’ is explained. The main goal of the support is to evaluate, include and plan inhabitant capacities. Inhabitant capacities are complex and can be measured in both the quantitative (income, tools, resources, etc.) as the qualitative spectrum (skills, knowledge, etc.). Therefore the proposed framework for the support in this article uses mixed methods.

### ***Framework for inhabitant, proximal and peripheral capacity evaluation***

In this section a framework is described to evaluate inhabitant capacities in relation to their built environment. Some of these capacities are easy to identify for both inhabitant and designer. Tools such as a hammer or saw can easily be found within the household and are directly related to the production of the house. The same counts for income or available resources such as: thatch, soil or wood. However, there are many capacities that are less obvious. Some capacities like tools, skills and resources are not directly related to the production of housing. This section will describe the steps required for the evaluation of inhabitant self-building, proximal and peripheral capacity evaluation. Each section starts with a summary (in italic) of what the chapter of the support tool entails. The support book is currently being published and will be available by 2018.

### ***Preparatory house and context mapping***

*“To better understand how the family currently lives and how they use their space, this section of the support explains how you can map, measure and draw: individual structures, interior, family compound and community area. Most of the rural families have more than one structure on the compound but still a multitude of functions are taking place outdoors. Some functions can be clearly identified (such as cooking) some are more difficult due to their temporal nature (studying). To be able to mark actions in the field (eating, washing, studying, etc.) you need detailed floor plans, section, façade views, interior (functions and furniture) of all the houses within the family compound and their surroundings. In this way during the observations (next section) you have the lines in which the activities take place. Most activities take place in and around the house, however, many of them also in the surroundings. To better understand important places in the surrounding (water points, school, church, etc.) and how they relate in terms of infrastructure, you will need to map the surroundings (max 0,5-1 km radius). The outcome of this section will offer a departure point for the design.”*

Before any capacity analysis can commence the general context of the location needs to be understood. This article will not debate the importance of mapping (de Jong & van der Voordt, 2002), various types or compare the benefits of mapping. It accepts that making an inventory of the existing context is common practice in design. However, it does state the importance for designers to start with a preparatory inventory to evaluate and localize inhabitant capacities. Therefore a general context inventory of the houses and family plot/compound needs to be made. This inventory can then be used to locate and contextualize inhabitant capacities gathered in observations and interviews (explained in the upcoming subsections). The in Appendix A described inventory starts with analysing the house(s) of the family within the context of their plot: measuring the individual structures to



produce facades, floor plans and sections sketches Figure 1; indicating the position of furniture, objects (containers, shoes, clothing, etc.) and openings (doors, windows and roof); gathering all information by drawing the plot with all individual structures.



Figure 1. Example inventory of a family on Mt. Elgon

Many of the inhabitant's capacities are peripheral: they do not own the resources and the resources are not located on their plot. They rely for substantially on the support of others to produce their built environment. Especially, skills and tools used in building the existing house are made available by neighbours, family, friends and community members (Smits, 2017). Therefore, it is essential to continue to make an inventory of the surrounding area. The next part of the described support (Community Area) emphasizes on an area in a 500-1000 meter radius around the family plot (see Figure 2). This 'initial' proximal and peripheral inventory helps to locate borders, water, infrastructure, trees, water points and general places of interest. It is aiming at helping the designer/engineer to get a general notion of the direct surroundings of the family. Based on the combined inventories (plot, proximal and peripheral) now both the family capacities and community capacities can be registered and located



Figure 2. Target area for context analysis on Mt. Elgon (500 meter radius) of approx. 50 families

### ***Observing inhabitants on their own and proximal capacities***

*"One of the most essential steps to design a new house is to better understand the existing*

*house. Besides the physical elements and their function (what you mapped in the previous section), there are many behavioural elements. We need to understand both in depth to grasp what preferences the family has and how they prefer to perform them. In this way you gain very detailed understanding what they prefer to do, where, when and how (for example where they wash, prepare food, fetch water, dry clothing, etc.). Obviously also what they do not prefer and would like to change in the future house. Before we can do so we will need to observe family members to understand their routine. The most important are the activities directly related to the house, compound and direct surrounding. The preferred method to perform such analysis is observation. Here an individual observes the behaviour (actions, movements, gestures, etc.) of an actor in its environment. This section explains how observations can be performed, what the difficulties are and how we advise you to perform your observation."*

In the previous subsection the area in which the capacities are being evaluated was explained. This subsection will elaborate how the first inventory of the capacities of the family in the everyday life can be made. This means looking at when, where and how capacities (resources, tools and skills) are used, stored or shared. It is important to understand that the presence of a visiting designer in such context has a tremendous effect on the inhabitant's behaviour. This might influence behaviour and ultimately the designer might misplace or misread the inhabitant's capacities. Therefore, to get an in-depth understanding, it is important to evaluate the inhabitants before *actively engaging*<sup>2</sup>. Observation is a suitable methodology to systematically record people's behaviour, actions and interactions (Hennink, Hutter, & Bailey, 2010). The level of engagement of the observer can normally range between participating fully in everyday activities (participant observation) and not participating at all in any activities (non-participant) observation. Although, it is commonly argued that not participating in practice does not exist, as the presence of an observer (person/camera/recorder) requires a level of participating.

Non-participant observation might theoretically give the most objective results, however the presence of the observer might suppress regular every day activities of the inhabitant (Hennink et al., 2010). On the other hand full participation in everyday activities (helping, asking, sharing, etc.) changes the behaviour as well. The support uses a partially engaged participant observation. Here, the observer can help in everyday activities, however, is requested to only engage in a supporting role (not sharing ideas, perspectives, etc.). To get a broad understanding on the capacities of the family as a whole, every family member will need to be observed for one whole weekday and one weekend day. Based on the previously made maps (inventory) the observer is able to mark where each capacity is registered (Figure 4).

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<sup>2</sup> To actively engage: any other methodology or action that requires direct interaction between designer and inhabitant.



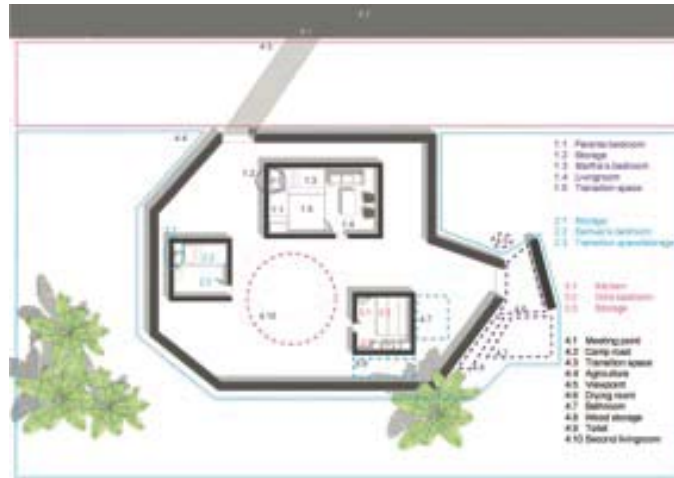


Figure 3. Example of a family compound on Mt Elgon

To help the observer note the various capacities a registration sheet was made to track the activities and related capacities during observations. Everyday activities such as cooking, cleaning, washing, water fetching, etc. show the inhabitants physical capacities (resources and tools) and how they are used in activities (skills). Although an observed capacity might not directly connect to the built environment the observer is able to register it and later decide on its possible use. At the end of the observation the observer is asked to add a picture, sketch or plan that explains, locates or proofs the described activity and capacities. Another important finding of the observation is to get a first notion of the social structures of the family (which shared activities do they have). These structures play a vital role in evaluating proximal capacities to the family. On a later moment identified families can be interviewed and their capacities evaluated.

TEAM: 1  
OBSERVATION: MOTHER  
DATE: 21-08-2017

Time	Activity	Duration	Where	With Whom	Skills, Tools, materials	Problems/chances/solutions	Comments	Map/Plan/Sketch/Picture
05:00	Arrival							

Figure 4. Example empty observation sheet

### Context depth analysis

*"To prepare for the design phase it is important to start analysing the context of your project in a more conventional approach. The mapping in chapter 7 helped to understand the surrounding, here the registered elements followed mainly on your own observations while walking in the area. Here places of importance, usage and behaviour are perceived with the least influence from local opinions (family, relatives and community members). After observing the family members in their daily activities your insights in the area changed substantially, hopefully in a more objective way. Now you can weigh your own initial observation with those of the family. In most cases this means you are able to analyse in a more detailed matter. Some of the analysis will focus on the direct surrounding of the family (compound & structures, ground) some on the community scale (garden, public areas, etc.) and some on the regional scale (available materials & climate)."*

After making the first context analysis of the house and spending substantial amount of time observing the activities of the family, the findings have to be located in a broader context of the community - starting by adding the identified capacities in the observation to the inventory shown in the first subsection, making a rich complete inventory of the family house and compound, registering; functions, orientation, usage, public/private relations, etc. Next steps in the support (see Appendix C) describe how to map: proximal capacities (locating identified capacities from the observation), building typologies (how capacities are articulated into a built form), available materials in the area (locate used building resources/capacities in the area: wood, soil, thatch, etc.), infrastructural capacities (water, firewood & electricity points, farmlands) and public areas.



Figure 5. Water points and electricity points

The results of this subsection enable the designer to articulate a comprehensive overview of the existing capacities of the family. Without an extensive conversation with the family, the designer observed most of this information in the families every day activities. The next subsection elaborates on which proximal and peripheral capacities the family and their community have.

### ***Interview inhabitants & community members on proximal and peripheral capacities***

*“In the previous chapter you assessed everything you could find in and around the family compound. All these elements together enable you to make valuable decisions, however the ownership and usefulness of the objects (resources) remain abstract. In order to clarify them in this chapter we will try to transform all available elements into capacities. Capacities are all things that possibly enable us to do or make certain things. In the realm of the built environment they can be described in 4 different categories: Resources (wood, grass, soil, etc. ), Tools (hammer, saw, machete, needle, brush, etc.), Skills/knowledge (weaving, digging, thatching, cooking, washing, etc.) & Income/labour (farmer, carpenter, cook, etc.). As engineers we need look in detail onto the capacities, which enable the family to build/maintain, a house. Specifically – to understand the difference between the house they have and the one they desire. Although the reasons might be complex and interrelated, at the end they all come down to the capacities they currently have and ones they do not have.*

*When you compare the desired capacities with the existing capacities most likely you will conclude that there is simply no way that they could build the desired house. In order to prevent insensitive decisions that are harmful to the inhabitants we have to better understand what the current capacities are and how we can use them/improve them to articulate solutions. This is what Michiel Smits has coined as capacity based decision-making. This decision-making process is based on three steps: Assess existing capacities of the family, Assess desired capacities of the family & Making decisions on improvements based as much as possible on existing capacities. In rural communities not only the individual but also the community’s capacities are important to the realized house. Family relations, friends and*

*neighbours are essential in most parts of realizing a house. For this purpose the interview in this section will help you to evaluate all capacities of both family and parts of the community they live in."*

After mapping and observing the family and their community the designer has a large inventory of capacities. This subsection intends to explore them in detail (ownership, costs, reward, quantity, etc.) by interviewing the inhabitants and their community. Therefore the support tool (Appendix D) helps the designer to setup a semi-structured interview. An informal or unstructured interview would give too much room for free interpretations and might cause blind spots in the capacity analysis. A structured interview would be too formal and might limit the inhabitants sharing on their capacities. An in-depth interview would allow too much detailed information about the capacities. Although very valuable, in this phase concisely described or quantified resource, tool and skill capacities are needed.

Materials/resources									
nr	item	amount	unit	comments	ownership	name of the owner	payment	if payed:specify	distance
1	clay soil	unlimited		soil for makng walls	family		free		none
2	timber	5	st	d=15cm, l=3m	family		free		1km
3	wood: post	11	st	150mm in diameter, l=3-4m	family		free		2km
4	dried grass	150	bundle	s (suitable for roofing)	family		free		1km
5	window	2	st	windows with iron bars 50x60cm	family		free		none
6	door+frame	1	st	ironsheet door with wooden frame door 1,80x0,8	family		free		none
7	water	unlimited	bucket	waterpoint	community	common	free		500m
8	clay soil	unlimited			community	Francis Kibue	free	free: fill up the whole with other soil	500m
9	rocks	unlimited		rocks for the foundation	community	common	free		1km
10	timber	15	st		community	Francis Kibue	paid	500 Ksh or give back the same within a year	2km
11	wood: post	5	st		community	Francis Kibue	paid	1000 Ksh or give back the same within a year	2km
12	dried grass	50	bundle		community	Francis Kibue	paid	100 Ksh per bundle or vegetables in comparable sum	2km
13	cement	unlimited	bag		other	shop	paid		5km

Figure 6. Example, overview capacities- materials

The designers are asked to prepare an interview instruction (based on a given example), which helps them to organize the interview. The instruction section assures that the interviewee is at ease (location, sitting, etc.) and understands the purpose of the interview (aim, topics, etc.). The interview guide section helps the designer to transform the capacities into logical questions for the interview. The questions of the interview guide are organized in four sections: resources, tools, skills/knowledge and income/labour. The support explains how interviews should be transcribed afterwards. This helps the designer to go through the answers afterwards and fill in a complete overview of all the capacities. After interviewing the family the designer is requested to repeat the process with the identified friends, family and community members that have certain capacities. Now have observed, mapped, located and quantified the capacities, we can use them to make decisions on future housing.

### Capacity informed decision-making

*"In the previous chapter you assessed the capacities of the family, their neighbours, friends, family and other community members. Most likely you now have an elaborate list of resources, tools, skills and many other things. The overview will be tremendous and to calculate and plan how to use it is difficult and a precision job. That's why this section describes the main support tool that was developed as a part of the PhD research of Michiel Smits. It will help you to weigh the options and identify the most suitable solution according to the available and desired capacities. Before we can start the comparison we will need to set some limitations. With too many variables you will be unable to properly compare*

options. Therefore, we begin by setting the three main limitations to the (framing) analysis; first of all, the finance. The family you are helping stated the amount of savings they have for building a new house. Secondly, is to set the time limitation.

The third import limitation is the estimated quantities used in the project. Without an existing design this is extremely difficult to set. For this purpose we ask you and the family to identify the minimal house measurements for the family to have an “improved” house. Most likely the dimensions will be comparable to the house they currently live in (as they are able to sustain life there) or you already set the dimensions during the dream house game. Based on the set floor plan you can make a sketch design of the new house. This model you will use in order to estimate possible capacities like: materials, transportation, tools, labour and to weigh various different options to see if they are more suitable according to the existing capacities of the family.”

The core argument of this article is that the main contributor to sustainable design is the use of available, proximal and peripheral capacities in articulating the built environment. As argued before capacities are complex and difficult to evaluate. Therefore, this article described the steps of a support tool that could be used by designers to evaluate those capacities via a mixed method approach. This section elaborates on the most important steps in the support that describes how these capacities can be used in what the author calls: *capacity informed decision-making* (see Appendix E). Here, the departure point for the design process is not defined by the functions, size or aesthetics, but by the available capacities of the family and their community.

In earlier sections of the support (not mentioned in this article) the designers organised ‘sessions’ with the family evaluating their desired house. The outcomes of this chapter describe: house typology, building methodology and materials. They are used to help the designer to compare the desired capacities (by the family) with their actual existing capacities. In the example below (Figure 8) the desired foundation phase was chosen of a family with extremely low financial capacities (less than 20.000 KsH to build an entire house; representative for the area on Mt. Elgon). Figure 8 indicates in red the problematic desired materials (costly materials and/or transportation). In the right columns the designer is able to list possible alternative materials found in the capacity analysis that are within the inhabitants reach, enabling the designer to openly discuss alternative materials with the family, exchanging ideas and elaborating why certain desired materials might be less suitable (considering families capacities) and why the alternatives are.

Materials (Required)	Quantities		Availability	Transport	Materials (Alternative)	Quantities		Availability	Transport
Branches	15	m1	yes	0	Branches	15	m1	yes	0
Marram Soil	1,32	m3	yes	500	Marram Soil	1,32	m3	yes	0
Cement	1396	kg	no	500	Clay soil	1,5	m3	yes	0
Riversand	2,828	m3	no	1000	Soil	2,828	m3	yes	0
Brick	600		no	1000	Stones	300		yes	0
Small Ballast (1/4 inch)	0,6996	m3	no	400	Marram Soil	0,6996	m3	yes	0
Transparent hose	8	m	no	0	Transparent hos	8	m	no	0
Mixed Soil	3	m3	yes	0	Mixed Soil	3	m3	yes	0
String	22	m	no	0	Sisal rope	22	m	yes	0

Figure 7. Weighing alternatives – materials

To make sure sufficient alternative materials for the new house are being considered, the designers are advised to make at least 2 alternatives. However, with alternative building materials come alternative tools, labour and skills. Therefore, the support explains how to generate an overview of the alternatives on all the capacities: resources, tools, skills/knowledge and income/labour. In Figure 9 an example of the alternative building tools is listed to show the differences in required capacities. The financial capacity is solely given to indicate how much the capacity would cost in case in it is not available.

Tools (Needed)	h	Available	Costs/Reward	Sum
Measure (ruler, tape: 1m1=0,5h)	11	no	1100	
Shovel (1m3= 8h)	130,42	yes		
Compacter (1m2= 0,5h)	12,1	yes	200	
Measure volume unit(container, wheelb	2	yes		
Trovel & flatboard	54	no	3500	
			4800	4800
Tools (Alternative)	h	Available	Costs/Reward	Sum
Measure (ruler, tape: 1m1=0,5h)	6	no	1100	
Shovel (1m3= 8h)	130,42	yes		
Compacter (1m2= 0,5h)	12,1	yes	200	
Measure volume unit(container, wheelb	2	yes		
Stone Hammer	26	no	2000	
			3300	3300
Tools (Alternative 2.0)	h	Available	Costs/Reward	Sum
Measure (with feet: 1m1=0,5h)	6	no	0	
Shovel (1m3= 8h)	130,42	yes		
Compacter (1m2= 0,5h)	12,1	yes	200	
Measure volume unit(container, wheelb	2	yes		
Break with stones	26	yes	0	
			200	200

Figure 8. Weighing alternatives – tools cost

After formulating at least two alternative solutions besides, the designers are asked to prepare a presentation for the family (Figure 10). Here, the designers present a sketch design solely based on capacities: resources, tools, skills/knowledge and income/labour. The typology, program and aesthetics of the sketch house are not considered in this presentation, solely the capacities. Per sketch design the designers are asked to clearly show what the needed capacities are and to what extent they suit the existing capacities of the family.



Figure 9. Presentation of the sketch design



After the presentation, there is an informal unstructured interview where the family can address all their questions and remarks about the presented designs, most likely indicating which elements they like about the individual designs and which they would like to include in their future house. The last part of the support advises the designer to gather all the results from the presentation and interview session and combine them into a final recommendation for the design phase. It contains all the resources, tools, skills/knowledge and labour that should be used in making the design. The support does not elaborate how the capacities should be used in articulating a design. It is firmly believed that by analysing the context, making an inventory of the capacities and weighing them against material alternatives gives a solid departure point for the design process. However, designing and building based on available proximal and peripheral capacities is complex and extremely difficult to organize. Tools have to be borrowed, materials exchanged and labour planned (what activity planned when and who will help with it). Therefore, in the last section of the support and also this article, the planning methodology is explained.

### **Planning with (available, proximal and peripheral) capacities**

*“In the previous chapters you were able to identify the capacities of the family and their community, formulate alternative desired houses (based on the capacities), make sketch designs, discuss the different chosen options by the family and finally use these in a final design proposal for their new house. Weeks of analysis, talking, observing and much more have come to an end. All you decided upon with the family has to be built by them, their family, friends, neighbours and other community members. All with your help, expertise and skills.*

*The key to a success realization for your project is in your grasp, however you will have to do one last preparation before you can start. Starting the foundation work without involving everyone that offered their resources, tools and skills might make them feel excluded from the project. This might cause them to redraw from the project leading to a lack of resources, tools and skills. Therefore this chapter will firstly advise you how to make a detailed planning. Secondly to prepare and present the future house of the family including a detailed planning when, who and what is needed of the community. Of course planning in rural areas is difficult and very complicated. With people struggling to meet ends every day. So although people really want to help they do not always remember what they agreed upon. Going through the planning regularly with the family and asking them to make sure the involved people are aware of what is expected two to three days in advance will majorly improve the success of the project.”*

With the design finalized and approved by the family, the designer is ready to start planning the building activities. The user/community capacity & participation planning section of the support describes how the designer can approach planning of the building activities. Here step by step the process is unravelled roughly into five phases: foundation, floor, walls, roof and finishes. Per building activity the designer states the capacities needed: materials, tools and labour. Indicating who (from the earlier made capacity analysis) has offered to help and for what reward. When the whole planning is finished the designer discusses the planning with the family and makes corrections if necessary (dates might not fit, resources might not be available, etc.).

When the planning is finalized it is time to present the planning to the community members that are listed in the planning. Per community member a small letter will be



handed out stating what is requested, by when and for what reward. The community members are asked to reply to the letter or ask any questions they might have. They are given time to discuss the requested capacities with their family members before they agree. As families struggle to generate the financial capacities to pay for help by the community, it is extremely important to enable the inhabitants to trade capacities instead of paying for them, offering each other a better habitation without the need of large savings and investments. This system of exchanging materials, labour and tools (capacities) need a thorough registration system. Most of the inhabitants on Mt. Elgon do not have the luxury to help each other without asking for something in return. Therefore, the last step of the support describes a registration system (logbook) where all borrowed capacities (tools, materials, labour) are registered in. At the end of each day a logbook is used to register the shared capacities. Per day, week or activity the inhabitant can write an "I owe you", clearly stating which capacity needs to be given back by when. This can be a certain amount of hours of digging, giving back six wooden posts by the end of the year, or a bag of maize by the end of the harvest season. This way is allowing a more flexible exchange system that follows the fluctuations in income, harvest and available time. Finally empowering the community to plan and realize a more self-reliant and improved built environment.

## **Conclusion**

This article explained the importance of capacity evaluation for sustainable design and development, concluding that there is a lack of a suitable framework to evaluate available, proximal and peripheral inhabitant capacities. It elaborated on the possible positive effects of available rural inhabitant capacities, proximal community capacities and peripheral capacities on the ecological footprint of their built environment. Continued by describing a framework that employs mixed methods to identify, contextualize and evaluate capacities in a rural Sub-Saharan context. Furthermore, it showed how these capacities can be weighed and used to formulate a capacity based sketch design. Concluding by describing how the capacity based design can be planned with the involvement of the inhabitants with their family, friend and their community.

The framework was developed to help designers advise rural communities in developing countries how they can realize a sustainable alternative housing based on their existing capacities. Opposing trend can be seen in developing countries where the 'western' example of building methodologies and materials is being used increasingly more often. Here, the ecological footprint of the inhabitants' built environment is growing exponentially which is in many ways becoming comparable to the formal unsustainable built environment seen in the West. Advising rural communities on the negative effects of pursuing unsustainable solutions and offering them sustainable alternatives, can potentially have a tremendous effect on making the built environment as a whole more sustainable. More importantly, it possibly sustains communities' resilience and social cohesion. Advocating the use of local available (sustainable) over industrialized (unsustainable) non-local materials potentially reducing emissions caused by the transport of non-local materials and labour. Although the described framework is not yet tested in practice, it will most likely allow effective evaluation of inhabitant capacities. As the support tool was written to assess inhabitant capacities in rural developing countries it can't yet be used in another context. However, the framework itself could be used to evaluate available inhabitant, proximal and peripheral capacities in different contexts.

The support is currently tested in a quasi-experiment setting (Shadish, Cook, & Campbell, 2002) in Sub-Sahara Africa. In two consecutive articles the framework for the quasi-experiments and the results of the impact of the support will be described.

## References

- Bribián, I. Z., Capilla, A. V., & Usón, A. A. (2011). Life cycle assessment of building materials: Comparative analysis of energy and environmental impacts and evaluation of the eco-efficiency improvement potential. *Building and Environment*, 46(5), 1133–1140. <http://doi.org/10.1016/J.BUILDENV.2010.12.002>
- Cambridge Dictionary. (2017). sustainability Meaning in the Cambridge English Dictionary. Retrieved September 25, 2017, from <http://dictionary.cambridge.org/dictionary/english/sustainability>
- Creswell, J. W. (2013). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*. SAGE Publications. Retrieved from <https://books.google.nl/books?id=PViMtOnJ1LcC>
- de Jong, T. M., & van der Voordt, D. J. M. (2002). *Ways to Study and Research Urban, Architectural and Technical Design*. IOS Press. Retrieved from <https://books.google.nl/books?id=tyDvAgAAQBAJ>
- Felce, D., & Perry, J. (1995). Quality of life: its definition and measurement. *Research in Developmental Disabilities*, 16(1), 51–74. [http://doi.org/10.1016/0891-4222\(94\)00028-8](http://doi.org/10.1016/0891-4222(94)00028-8)
- Hamer, B., & Bergmark, J. (2003). *Kitchen Stories (2003)*. Retrieved from [http://www.imdb.com/title/tt0323872/?ref\\_=nv\\_sr\\_1](http://www.imdb.com/title/tt0323872/?ref_=nv_sr_1)
- Hennink, M., Hutter, I., & Bailey, A. (2010). *Qualitative Research Methods*. SAGE Publications. Retrieved from <https://books.google.nl/books?id=rmJdyLc8YW4C>
- Lélé, S. (1991). Sustainable development: A critical review. *World Development*, 19(6), 607–621. Retrieved from [http://linkinghub.elsevier.com/retrieve/pii/0305750X9190197P%5Cnpapers2://publication/doi/10.1016/0305-750X\(91\)90197-P](http://linkinghub.elsevier.com/retrieve/pii/0305750X9190197P%5Cnpapers2://publication/doi/10.1016/0305-750X(91)90197-P)
- Page, T. (2014). Product attachment and replacement: implications for sustainable design. *International Journal of Sustainable Design*, 2(3), 265. <http://doi.org/10.1504/IJSDES.2014.065057>
- Shadish, W. R., Cook, T. D., & Campbell, D. T. (2002). From: Shadish, W., Cook, T. & Campbell, D (2002) Experimental & Quasi-Experimental Designs for Generalized Causal Inference. Boston: Houghton Mifflin. *Experimental and QuasiExperimental Designs for Generalized Causal Inference*, 127(2002), 64–102.
- Smits, M. (2017). *Field Research I Mt. Elgon*.
- UN-Habitat. (2015). HABITAT III ISSUE PAPERS 22 – INFORMAL SETTLEMENTS. In *Habitat III Issue papers: 22-informal settlements* (p. 9). Retrieved from [https://unhabitat.org/wp-content/uploads/2015/04/Habitat-III-Issue-Paper-22\\_Informal-Settlements.pdf](https://unhabitat.org/wp-content/uploads/2015/04/Habitat-III-Issue-Paper-22_Informal-Settlements.pdf)
- Van Vuuren, D. P., & Bouwman, L. F. (2005). Exploring past and future changes in the ecological footprint for world regions. *Ecological Economics*, 52(1), 43–62. <http://doi.org/10.1016/J.ECOLECON.2004.06.009>
- Vargas Hernandez, N., Okudan Kremer, G., Schmidt, L. C., & Herrera, P. R. A. (2012). Development of an expert system to aid engineers in the selection of design for environment methods and tools. *Expert Systems With Applications*, 39, 9543–9553. <http://doi.org/10.1016/j.eswa.2012.02.098>
- Wackernagel, M., & Rees, W. (1998). *Our Ecological Footprint: Reducing Human Impact on the Earth*. New Society Publishers. Retrieved from <https://books.google.co.ke/books?id=WVNEAQAAQBAJ>

*Chapter 2:*  
*Building Performance Evaluation (BPE)*  
*Indoor Environmental Quality (IEQ),*  
*health and wellbeing*  
*Post Occupancy Evaluation (POE)*

# Value Architecture (VArch): As another Approach of Value Engineering (VE)

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**Abstract:** Architecture has principles and unique design basis, which support the building with physical and nonphysical functions forming its shape by using the effective structure system in the presence of appropriate technology. Besides, the necessity of conserving energy, is to achieve savings on the long-run and satisfying the need of occupants, directing towards sustainability. Value in architecture is therefore not only a necessity of modern living, but also a cultural status of a developed society. It therefore goes beyond the basic human needs with minimum costs including “Art” in its own definition. This makes it is important to know “how to measure and quantify value architecture for architectural projects.

This study aims to clarify the concept of Value Engineering in construction industry, and its shortages in fulfilment of architectural values. A new term which is called “Value Architecture” has been proposed, which covers the shortcomings of evaluating the architectural values of projects to ascertain the validity of the hypothesis which is “Value Architecture is a more effective tool used to evaluate architectural projects than Value Engineering”. Therefore, a methodology is proposed to evaluate the architectural buildings during the contracting phase from the point of view of Value Architecture, considering that the main axes of Value Architecture are: (Ideal Functional Performance “physical and non-physical” - Ideal Cost).

**Keywords:** Value Engineering (VE), Value Architecture (VArch), Sustainability, (Physical or Non-Physical) Function, Ideal Costs.

## Framework

### *Introduction*

Value Engineering (VE); is the ratio of function to cost. Therefore value can be increased by either improving the function, reducing the cost or both. The major reasons for choosing VE, to achieve cost saving, and provide creative thinking for design improvement.

On the other hand, Culture and civilization are printed on the face and organization of buildings, making architecture one of the important aspects of human development. Creating architecture involves art, aesthetics, science, engineering, sustainable values, beliefs, friendship and team-working.

### *Research Problem*

The main research problems is: Value Engineering is not qualified enough to measure qualitative architectural values as it is ignoring some effective Non-physical functions.

### *Research Objectives*

The research aims:

- Finding a suitable method for evaluating and quantifying, in financial terms, the value of architectural work.
- Proposing a more effective tool “A new concept” to evaluate the value of architectural work than Value Engineering.

### Research Question

The research question that is used to determine Value Architecture, is:

“Can we define a suitable method for evaluating and quantifying, in financial terms, the value of architectural work?”

### Research Hypothesis

The main hypothesis of the research is that “Value Architecture is a more effective tool used to optimize the value and life cycle cost of the architectural project than Value Engineering” as Value Engineering is ignoring some effective Non-physical functions.

$$\text{Value Engineering "Physical Values"} = \text{Function} / \text{Cost (LCC)} \quad (\text{ICE, 1996}).$$

Other Wise

$$\text{Value Architecture "Physical \& Non-physical values"} = (\text{Physical \& Non-physical}) \text{Function} / \text{Cost}$$

### Research Methodology

The research proposed a methodology as in the following in figure 1:

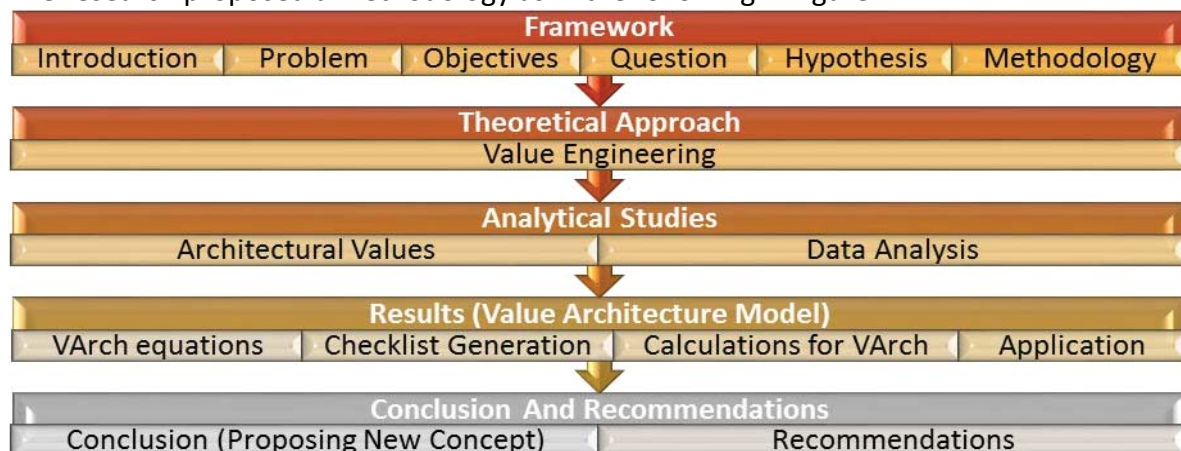


Figure 1. Research methodology. (Source: Researchers)

### Theoretical Approach

It is important to identify Value in general to understand the main points that value engineering and architectural values revolve around.

### Value in General

It has different meanings for different people as (Thiry, 1997):

- The customer will regard it as the "best buy"
- The manufacturer will consider it as "the lowest cost"
- The designer will view it as the "highest functionality".

$$\text{Value} = (\text{Function in a good Quality}) / \text{Cost (LCC)}$$

From previous equation, value increases by improving either function, reducing cost or both. A balance between value elements is required to achieve best value for money (Dell'Isola,1997).

### Value Engineering

The success of VE process is due to its ability to identify opportunities to remove unnecessary costs while assuring performance and other critical factors that meet customer's expectation.

### **Definition of value engineering**

It is an organized effort directed to analyse the functions of systems, products, standards, specifications, practices and procedures, to satisfy the required function at the lowest cost of ownership without reducing needed quality (Elsanabary, 2004). It can be applied during project idea or after completion of public perception (Bythaway, 1992).

### **Objectives of value engineering**

VE can save (money and energy), reduce (time, wastage of resources, conflict and risks), improve (quality, and performance) and eliminate unnecessary cost. (Bhokare, 2017).

### **Fundamentals of value engineering**

Function in good quality and cost are the VE fundamentals, which is discussed as the following:

*Function (Performance/Functionality):*

- It is the primary purpose for which the product was found (Ilayaraja et al., 2015).
- According to FAST “Function Analysis System Technique” diagram model, which is used to eliminate unnecessary costs, functions are analyzed to:
  - Basic “Main” function which represents specific main target required to be followed.
  - Secondary function which target can be obtained without it.
  - Required secondary function which is necessary to achieve the basic function.

### **Life-Cycle Costs**

It associated directly with constructing and operating buildings (Ilayaraja K. et al., 2015).

### **Phases of value engineering**

Value engineering is a practical study which makes its employees need to attend meetings and workshops to acquire a detailed value study for a project. The following figure 2 clarifies the techniques and the tasks involved in each phase as the following (Bhokare, 2017):

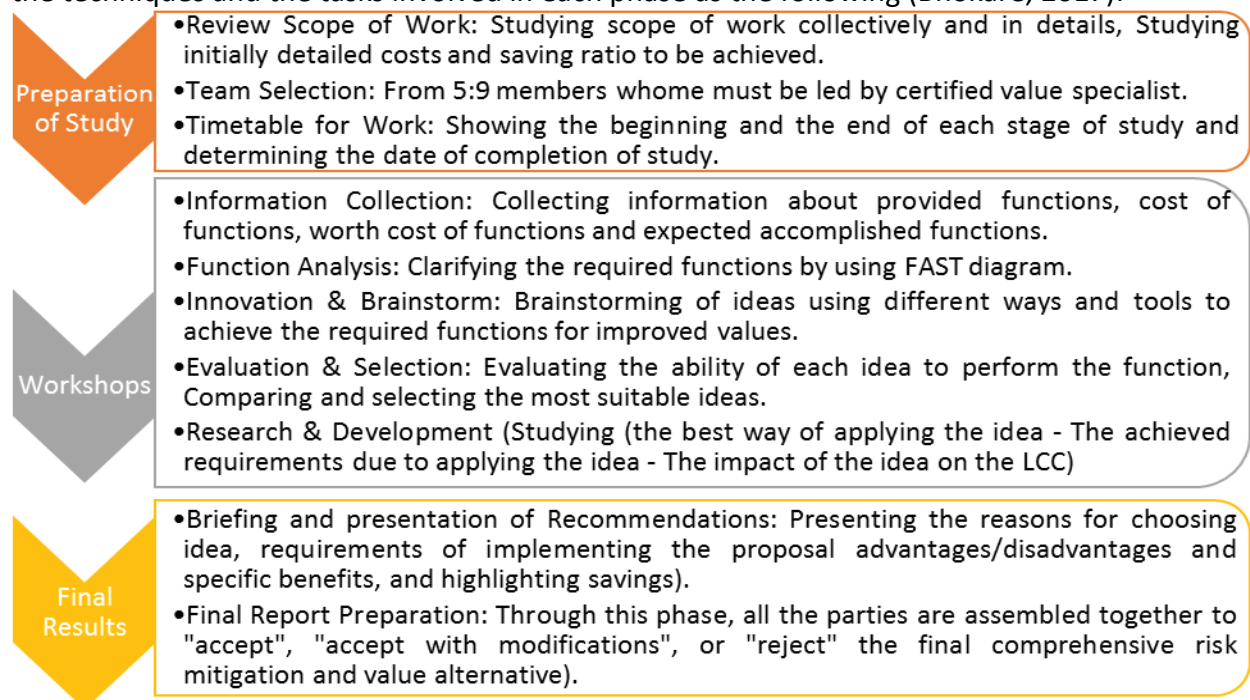


Figure 2. Phases of Value Engineering. (Source: Dell'Isola, 1982, Edited by Researchers)



## Analytical Studies

### Definition of Urban and Architectural work

Urban and architectural buildings are compatible with human needs. The human's (Environmental, psychological, cultural, and social) Composition, is the determinant key of design, taking into account the physical and non-physical values which are as the following:

### Architectural Values (Physical and Non-physical values)

There are many values associated with introducing architectural work and compatible with humanitarian needs such as the following:

#### Functional values

There are different categories for Functional (Physical and non-physical) values presented in the following figure 3:

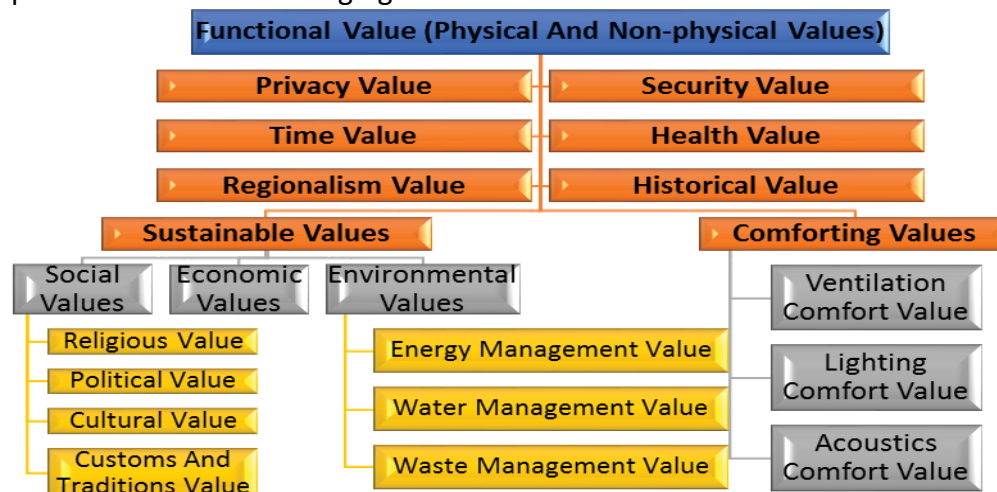


Figure 3. Functional values (Physical and Non-physical values). (Source: Researchers)

#### ➤ Privacy value:

The right to privacy is a universal human right (Movius et al., 2009). It is also used to control the passage of light and airflow while maintaining privacy (Abdel Gelil, 2006).

#### ➤ Security value:

It is the condition of being protected from harm or other non-desirable outcomes. It is also called "controls," and sometimes include changes to the threat (OSTMM).

#### ➤ Historical value:

It is value acquired to a building which is (related to national historical aspects or events - established by an important person - globally built from a long time) (Hume, 1965).

#### ➤ Time value:

It can be linked to an experience of a sense of taste, collective consciousness and unconsciousness, generating an aesthetic style related to that time (Brolin, 2000).

#### ➤ Health value:

It is responsible for ensuring a healthy living environment, through selection of appropriate materials (Frank et al., 2003).

#### ➤ Regionalism value:

This design value is based on the belief that building should be designed in accordance with the particular characteristics of a specific place (Gelernter, 2004).

#### ➤ Comforting values: (Ventilation, Lighting and Acoustics)

The personal nature of positive associations, psychological comfort is highly subjective (Kolcaba, 2003). Comforting value can be reached by the following:

- ❖ Ventilation comfort which means maximizing natural ventilation and renewed artificial ones without wasting energy.
- ❖ Lighting comfort which means maximizing the amount of sunlight that reaches the structures and using artificial lightning without wasting energy (Frank, 2003).
- ❖ Acoustical comfort which means minimizing noise pollution, and maximizing the needed sounds reaching to an acoustics comfort zone (Beatley et al., 2004).
- Sustainable values
  - ❖ Economic value means the amount of performed benefit to satisfy needs (Perry,1926).
  - ❖ Environmental values concerns with introducing "eco-regulations concerning with sustainability"(Cuff, 2000). It consists of four values, which are as the following:
    - Energy Management value: It started as a cost saving, but is now becoming a strategic part of the company's larger corporate social responsibility program.
    - Water Management value: Scientists warn that the effects of climate change are escalating risks to water supplies, so it is important to study how to preserve it.
    - Waste Management value: It is involved in landfill gas utilization. Its operations consist of environmental protection, air and gas management (Wikipedia).
  - ❖ Social values are Focusing on exaggeration, dazzling and self-affirmation in relation to the past (Hamouda, 1986). It consists of four values, which are as the following:
    - Religious value: It deals with all values as the main engine for all fields of life, taking into account the graduation of values by the ratios of goals with absolutely single strong power which is the holy god "ALLAH" (Gelernter et al., 2004).
    - Political value :It represents value related to the policy of treating the individual as a member of society with governance affairs.
    - Cultural value: The cultural background reflects the nature of human, creates distinctive aesthetical expressions (Amundson et al., 2004). So all social values cannot be expressed in isolation from the culture of the individual.
    - Customs and Traditions value: It is the preferred typology for buildings, because they "create" timeless and "functional" designs (Beatley et al., 2004).

#### *Formational values*

There are different categories for Formational values presented in the following figure 4:



Figure 4. Formational Values. (Source: Researchers)

- Land mark value:

It represents a building of unique architectural style, unique architectural design or unique artistic creativity or a scientific or technical value of construction (Craven, 2017).
- Surface treatment value:

Depending on the use of lighting (natural or artificial), shades, Shadows, colours, texture or contrast between them, to give an unprecedented perception and impact of the formation.

➤ Symbolic value:

It represents a building associated with a person that had a clear impact on the society, or a building which characterized by architectural design for one of the Pioneers of Architecture (Wikipedia).

➤ Aesthetic value:

These aesthetic values are due to the development that has taken place in the art community, Designers' tendency to experiment with form, materials, and ornament to create new aesthetic styles and aesthetic vocabulary (Wikipedia).

➤ Fulfillment of function value:

A building or product form shall be shaped on the basis of its intended function, often known as "form follows function".

➤ The simplicity and minimalism design value:

This design value is based on the idea of simple forms. It represents forms which are both truer to "real" art and represents "folk" wisdom (Toy, 1999).

➤ Preservation and Restoration value:

Creating a connection between past and present forms of building. This value is also often related to preserving and creating regional and national identity (Lefaivre et al., 2003).

➤ Vernacular value:

A simple life and its design, closely linked to nature (Oliver, 2004).

### Structural Values

There are different categories for Structural values presented in the following figure 5:

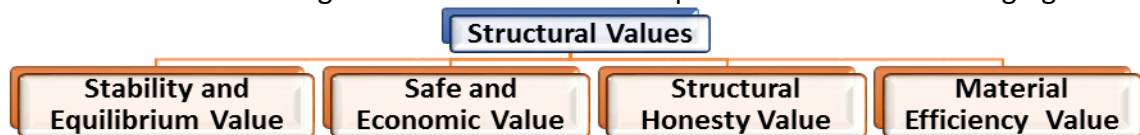


Figure 5. Formational Values. (Source: Researchers)

➤ Stability and equilibrium value

It concerns the stability of systems. Structural stability can be informally defined as "The power to recover equilibrium".

➤ Safe and economic value

Achieving savings in total costs by using a material within a safe structural system which is characterized by low maintenance, high durability, and low life cycle cost.

➤ Material efficiency design value

It implies that materials should be used and selected according to their properties, and that the characteristics of a material should influence the form it is used for (Nesbitt, 1996).

➤ Structural honesty design value

Structural Honesty is linked to the notion that a structure shall display its "true" purpose and not be decorative etc. (Brolin, 2000)

### Technological Values

There are different categories for technological values as in the following figure 6:



Figure 6. Technological Values. (Source: Researchers)

➤ Appropriate technology value:

Using appropriate technology to fulfil physical and non-physical needs, to 'Sustain the Life Conserving System', to achieve a valid design for the upcoming generations (Wikipedia).

➤ Available technology value:

It depends on the availability of the construction material, construction equipment, local labors, and available maintenance in the same area of construction

➤ Local technology value:

It supports local production and consumption of goods, local control of government, and promotion of local history, local culture and local identity.

➤ Latest technological value:

It depends on using the latest technology to offer various values, as the following:

- ❖ Time Saving Value: It means making it possible to do something quickly: causing something to happen or end faster (Merriam Webster dictionary), reducing the amount of time needed for doing something (Cambridge dictionary).
- ❖ Cost Saving Value: An action that will result in fulfilment of the objectives of a purchase, at a cost lower than historical cost or projected cost (Business dictionary).
- ❖ Durability Value: The ability to exist for a long time without significant deterioration in quality or value (Merriam Webster dictionary).
- ❖ Accuracy Value: It is the degree of closeness of measurements of a quantity to that quantity's true value (Wikipedia).

### **Data Analysis**

From previous we can deduce that the general function is consists of four main categories which are (Architectural - Formational- Structural- Technological) Functions. General function can be also expressed by two words (verb + noun) to facilitate the comparison of alternatives and cost variants. Functions are classified into:

- ☐ Physical function: representing (verb + Quantitative noun), it provides adscription of a work function which are as the following (Support Weight – Transmit Load).
- ☐ Non-Physical function: representing (verb + Qualitative noun), it provides adscription of aesthetic function, as the following (Attract Attention – Improve Appearance).

### **Result “Value Architectural Model”**

#### **Value Architecture equations**

From previous, general equation for Value Architecture is as the following (Researchers):

$$\text{Value Architecture} = (\text{Physical \& Non-physical}) \text{ General Function} / \text{Cost}$$

Previous equation can be divided into four equations which are as the following:

Functional Value Architecture = Architectural Function / Cost.	eq. (1)
Formational Value Architecture = Formational Function / Cost.	eq. (2)
Structural Value Architecture = Structural Function / Cost.	eq. (3)
Technological Value Architecture = Technological Function / Cost.	eq. (4)

#### **Value Architecture checklist generation**

The following checklist (in table 1) is a brief for the values governing architectural work. This checklist will be given to the designer to test the availability of values in each idea.

So, on practicing VArch process, values are constant by replacing this idea by a saving one.

Table 1. Architectural values Checklist Generation and an applied case study. (Source: Researchers)

Idea on which Value Architecture will be applied.							Idea	
Physical and Non- Physical) Values Governing Architectural Work	Functional values	Privacy Values					√ or X	√
		Security And Safety Values					√ or X	√
		Historical Value					√ or X	x
		Time Design Value					√ or X	x
		Health Value					√ or X	x
		Regionalism Design Value					√ or X	x
		Comforting Values	Ventilation Comfort				√ or X	√
			Lighting Comfort				√ or X	x
			Acoustical Comfort				√ or X	√
		Sustainable Values	Economic Values				√ or X	√
			Environmental Values	Energy Management Value			√ or X	x
				Water Management Value			√ or X	x
				Waste Management Value			√ or X	x
			Social Values	Religious Value			√ or X	x
				Political Value			√ or X	x
				Cultural Value			√ or X	√
				Customs & Traditions			√ or X	√
		Others					√ or X	x
	Formational Values	Land Mark Value					√ or X	x
		Surface Treatment Value					√ or X	√
		Symbolic Value					√ or X	x
		Aesthetic Values					√ or X	√
		Fulfilment Of Function Value					√ or X	√
		The Simplicity And Minimalism Design Value					√ or X	√
		Preservation And Restoration Value					√ or X	x
		Vernacular Design Value					√ or X	x
		Others					√ or X	x
	Structural Values	Material Efficiency Design Value					√ or X	√
		Structural Honesty Design Value					√ or X	√
		Stability And Equilibrium Value					√ or X	√
		Safe And Economic Value					√ or X	√
		Others					√ or X	x
	Technological Values	Available Technology Value					√ or X	√
		Appropriate Technology Value					√ or X	√
		Local Technology Value					√ or X	√
		Latest Technological Value					√ or X	x
		Others					√ or X	x
This checklist is an applied case study for residential bed room door design. It was answered by an architect who is specialised in residential designs.								

This checklist is an applied case study for residential bed room door design. It was answered by an architect who is specialised in residential designs.

√ Means required to be achieved. X Means unrequired to be achieved.

Others means any other added values depending on future research.

### Calculations and Selection of the saver ideal idea

This step is concerned with linking (Physical & Non-physical) architectural General Function to the actual cost, then comparing it to the worth cost reaching to the Value coefficient which is determined by:

$$\text{Value Architecture coefficient} = \text{Actual cost} / \text{Worth cost}$$

If the architectural values are constant and the coefficient is more than one, this will indicate that the replace idea is better than the present one.

∴ Actual cost is the cost of the original idea. ∴ Worth cost is the cost of the replaced idea

Table 2. Calculations and Selection of saver ideal idea (Source: Researchers).

Divisions*	Description	Architectural Values**	Actual Price	Replaced Idea	Worth Price	VArch coefficient
General Requirements						
Site Construction						
Concrete						
Masonry						
Metals						
Wood & Plastics						
Thermal & Moisture Protection						
Doors & Windows						
Finishes						
Specialties						
Equipment						
Furnishings						
Special Construction						
Conveying Systems						
Mechanical						
Electrical						

\* Master Format divisions is a standard for organizing specifications and other written information which is organized in a standardized outline format within number of Divisions, each Division is subdivided into a number of Sections (Spiegel, 1999). Divisions will be updated upon development of master format.

\*\* Constant achievable Physical and Non-physical Architectural values.

### ***Applied Case Study***

The research suggests a brief Case Study which is “Residential Door Design”, despite its small size, it is a part of a building and easy to be visualized in terms of the (physical and non-physical) functions of its parts linked to its costs. Value Architecture Model can be applied through several stages which are as the following:

#### **Step 1: Defining fixed architectural values for each design idea.**

The designer sets the architectural values for each idea, according to (functional, formational, structural and technological) functions, which shouldn't be changed on replacing this idea by a saving idea, as shown in table 1.

#### **Step 2: Defining the basic components of the residential door (This is step is similar to VE).**

Defining the main components of the residential door which can be replaced by a saving one to achieve the same physical and non-physical architectural values. The door's main components are: Hollow Metal, Knob, Door Hinges, Lock, Finishing Materials and Door Frame.

#### **Step 3: Defining the architectural values of each component of the residential door.**

Defining the main physical and non-physical architectural values of each components according to (functional, formational, structural and technological) Functions, to achieve the designer's main architectural values.



Step 4: Calculating the actual cost for each component (This is step is similar to VE).

Costs of the each component is estimated including materials, installation and total cost which is similar to the detailed contractor's estimation that is presented in the Tender (bid) documents and specifications.

Step 5: Novelty and Brainstorming of ideal ideas.

Brainstorming of ideal ideas on all the possible ways to achieve the required physical and non-physical architectural values.

Step 6: Calculations and Selection of the saver ideal idea.

The original door is made from American filler oak wood. This door is heavy, so it will need strong copper hinge and strong wooden frame. The replaced idea is made from MDF board coated by 6mm thick PVC surface with oak wood texture. This door have the same form carrying the same values but it is light enough to be carried by metallic hinge covered by copper layer and light MDF frame.



Figure 7.  
Original door.



Figure 8. Replaced door and frame.  
Hexagon shape gives more stiffness with light weight.

Source:

<http://www.cesadoor.com.tr/en/home.html>

Table 3. Calculations and Selection of saver ideal ideas for residential door design idea (Source: Researchers).

Div.	Description	Architectural Values	Actual Price	Replaced Idea	Worth Price	VArch coefficient
Door Division	<b>Door shutter/ leaf</b> made from American filler oak wood.	Privacy, Security and safety, Ventilation and Acoustical Comfort, Cultural , Customs And Traditions, Surface Treatment, Aesthetic, Fulfilment Of Function, Simplicity And Minimalism Design , Material Efficiency Design, Structural Honesty Design, Stability And Equilibrium, Available, Appropriate and Local Technology Values.	<b>10000 LE</b>	MDF board coated by 6mm thick PVC surface with oak wood texture.	<b>5000 LE</b>	$\frac{1000}{5000} = 2$
	<b>Knob</b>	Privacy, Security and safety, Available, Appropriate and Local Technology Values.	<b>100 LE</b>	---	---	---
	<b>Strong Copper Hinges</b>	Stability and Equilibrium, Safe And Economic, Available, Appropriate and Local Technology Values.	<b>100 LE</b>	Metallic	<b>50 LE</b>	$\frac{100}{50} = 2$
	<b>Lock</b>	Privacy, Security and safety, Available, Appropriate and Local Technology Values.	<b>20 LE</b>	---	---	---
	<b>Finishing Materials</b>	Security and safety, Available, Appropriate and Local Technology Values.	<b>600 LE</b>	Transparent Polishing	<b>100</b>	$\frac{600}{100} = 6$
	<b>Strong Wooden Frame</b>	Stability And Equilibrium, Available, Appropriate and Local Technology Values.	<b>500 LE</b>	MDF Frame	<b>300LE</b>	$\frac{500}{300} = 1.6$

Note that: 18LE is equivalent to 1\$ according to the Egyptian Central Bank (18-11-2017).

From table 3, we can deduce that the replaced ideas carrying the same values with lower cost price - reaching to 16% of the original price- is better than the original ones.

## Conclusions and Recommendations

Simply stated, Value Engineering is more than a cost-reduction methodology, it is a systematic approach for identifying and solving problems. Value architecture is more than all of that, as it concerns with the best performed function with its main classifications (Physical and Non-physical) functions with ideal costs.

### Conclusions

From all above, we can deduce the following:

- a. Quality, (Physical and nonphysical) Function and Cost are the fundamentals of **Value Architecture**.
- b. **Value Architecture's** goals are:
  - Save money, resources, time and manpower by eliminating unnecessary or excessive cost without sacrifice quality or function.
  - Improve quality and increase Reliability, Maintainability and Performance.
- c. The Checklist which obtained by the research will be given to the designer of the project before starting the "**Value Architectural (VArch) Analysis**" to obtain the real need behind each element in the project.
- d. A questionnaire or special interviews is a must as a part of "VArch Analysis" to quantitate the value of functions according to user's desire. For example: The value of a piece of land adjacent to a person's house and he needs it to expand his house considerably higher than its value for someone else.
- e. New concept "Value Architecture" is generated by the research, which is as the following:

Value Architecture (VArch) is finding the right balance between architectural investments components (Function – Form – Structure –Energy – Time - Cost) by an appropriate technology to meet today's requirements, un-ignoring the future needs.

### Recommendations

These findings were translated into a group of recommendations, which are as the following:

- Transforming the **Checklist** which is obtained by the research into a quantitative numerical assessment.
- Developing a program to facilitate the assessment of **Value Architecture** for buildings
- Studying the ability of applying **Value Architecture** on different kinds of buildings as Smart buildings, Sustainable buildings and high tech buildings.
- Introducing new courses in universities specially **Value Architecture** and its role in assessment architectural buildings.

### References

- Abdel Gelil, N. (2006). *A New Mashrabiyya for Contemporary Cairo: Integrating Traditional Latticework from Islamic and Japanese Cultures*. *Journal of Asian Architecture and Building Engineering*, Volume 4.
- Amundson, J. A. & Miller, C. C. (2004). *Classicism*. In Sennott, R. S. (Ed.) *Encyclopaedia of 20th century architecture*. New York: Fitzroy Dearborn.
- Beatley, T. & Wheeler, S. M. (2004). *The sustainable urban development reader*, London, Routledge.
- Bhokare, S. A., Chavhan, B. R., Kolhe, S. G. & Tatwawadi, R. S. (January 2017). *Value Engineering in Construction*. *International Advanced Research Journal in Science, Engineering and Technology* Vol. 4.

- Brolin, B. C. (2000). *Architectural ornament: banishment and return*. New York: Norton.
- Business dictionary. Retrieved September 15, 2017, from the World Wide Web: <http://www.businessdictionary.com/definition/cost-saving.html>.
- Bythaway, C.W. (1992). *FAST- An Intuitive Thinking Technique*. New York: SAVE Conference Proceedings. Phoenix. Arizona.
- Cambridge dictionary. Retrieved September 15, 2017, from the World Wide Web: <http://dictionary.cambridge.org/dictionary/english/timesaving>.
- Craven J. (2017). *Architecture and Design - Exploring What They Are*. Retrieved September 15, 2015, from the World Wide Web: <https://www.thoughtco.com/what-is-architecture-178087>
- Cuff, D. (2000) *Epilogue*. Kostof, S. (Ed.) *The Architect: chapters in the history of the profession*. USA: Berkeley, Calif., University of California Press.
- Dell'Isola A. J. (1982). *Value engineering in the construction industry*. USA: Van Nostrand Reinhold.
- Dell'Isola, A. (1997). *Value Engineering: Practical Applications for Design, Construction, Maintenance and Operations*. USA: Wiley.
- Elsanabary. M. (2004). *Application of construction management in irrigation projects Utilizing VE techniques*. Master. Egypt: M.Sc. Thesis. Suez Canal University.
- Frank, L. D., Engelke, P. O. & Schmid, T. L. (2003). *Health and community design: the impact of the built environment on physical activity*. Washington: Island Press.
- Gelernter, M. & Dubrucq, V. (2004). *Regionalism: Encyclopedia of 20th Century Architecture*. New York: Fitzroy Dearborn.
- Hamouda, O. (1986). *Architectural character between the origin and the contemporary in Egypt*. Egypt: PhD thesis, Helwan University, Faculty of Fine Arts.
- Herzog P. (OSSTMM) *Open Source Security Testing Methodology Manual*. Retrieved September 15, 2017, from the World Wide Web: <http://www.isecom.org/research/osstmm.html>
- Hume, D. 1965. *Of the Standard of Taste and Other Essays*. New York: Edited with an introduction by Lenz, J. W., Bobbs-Merrill Company.
- Ilayaraja K. & Eqyaabal Z. (November 2015). *Value Engineering in Construction*. Indian journal of science and technology, Volume 8, pp. 32.
- Institution of Civil Engineers ICE. (1996). *ICE design and practice guides: Creating Value in Engineering*. Britain: Edition illustrated. Thomas Telford.
- Kolcaba, K. (2003). *Comfort Theory and Practice: A Vision for Holistic Health Care and Research*. New York: Springer Publishing Company.
- Lefaivre, L. & Tzonis, A. (2003) *Critical regionalism: architecture and identity in a globalized world*. USA: Munich, Prestel.
- Merriam Webster dictionary. Retrieved September 15, 2017, from the World Wide Web: <https://www.merriam-webster.com/dictionary/durable>.
- Merriam Webster dictionary. Retrieved September 15, 2017, from the World Wide Web: <https://www.merriam-webster.com/dictionary/time-saving>.
- Movius, L. Krup, N. (2009). *U.S. and EU privacy policy: comparison of regulatory approaches*. International Journal of Communication, Volume 3, pp. 169–187
- Nesbitt, K. (1996). *Theorizing a new agenda for architecture: an anthology of architectural theory 1965-1995*. New York, Princeton Architectural Press.
- Oliver, P. (2004) *Vernacular Architecture*. In Sennott, R. S. (Ed.) (2004). *Encyclopaedia of 20th-Century Architecture*. New York: Fitzroy Dearborn.
- Perry, R.B. (1926). *General Theory of Value*. New York: Lonman, green. Pp. 6
- Spiegel, R. & Meadows, D. (1999). *Green Building Materials: A Guide to Product Selection and Specification*. New York, John Wiley & Sons, Inc.
- Thiry, M. (1997). *Value Management Practice*. USA: Project Management Institute.
- Toy, M. (1999). Editorial. In Toy, M. (Ed.). *Aspects of minimal architecture II*. London: Academy Editions.
- Wikipedia: Accuracy and precision. Retrieved September 15, 2017, from the World Wide Web: [https://en.wikipedia.org/wiki/Accuracy\\_and\\_precision](https://en.wikipedia.org/wiki/Accuracy_and_precision)
- Wikipedia: Appropriate Technology. Retrieved September 15, 2017, from the World Wide Web: [https://en.wikipedia.org/wiki/Appropriate\\_technology](https://en.wikipedia.org/wiki/Appropriate_technology).
- Wikipedia: Architectural design values. Retrieved September 15, 2017, from the World Wide Web: [https://en.wikipedia.org/wiki/Architectural\\_design\\_values?oldid=663738226](https://en.wikipedia.org/wiki/Architectural_design_values?oldid=663738226)
- Wikipedia: Waste Management. Retrieved September 15, 2017, from the World Wide Web: [https://en.wikipedia.org/wiki/Waste\\_Management\\_\(corporation\)](https://en.wikipedia.org/wiki/Waste_Management_(corporation)).

# Passive Cooling Design Strategies for Retrofit of Residential Tower Blocks in Northern Cyprus

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**Abstract:** This research investigates potential passive design strategies for improving the thermal performance of existing residential tower block (RTB) in Famagusta, Northern Cyprus. In a Mediterranean island that experiences hot and humid temperatures throughout the year, residential buildings need to be adaptable to the climate in order to improve the thermal comfort of occupants. The current housing stock includes a prevalence of high density, medium and low-rise residential tower block developments without implementing any insulation materials. The objective of this study is to develop and test passive cooling design strategies into retrofitting ill-performing residential tower blocks in the coastal city of Famagusta. As an initial step, the performance of a case study was modelled and simulated via employing Integrated Environmental Solutions - Virtual Environment (IES-VE) software add-ins Apache-Sim Dynamic Thermal Simulation. The results from the base case model were analyzed according to the adaptive comfort of CIBSE Technical Memorandum 52 guidelines: The Limits of Thermal Comfort – Avoiding Overheating in European Buildings. The spaces studied (living room and bedrooms) within the case study sample flats were observed to exceed the acceptable limits of thermal comfort; particularly living rooms with this zone exceeding the upper limit for overheating by up to 9 hours daily. The main reasons for the problematic thermal performance were identified as resulting from: infiltration through the building fabric, the lack of sufficient ventilation through the living spaces and excessive heat gains through the large areas of glazing. The internal operating temperatures of the simulated flats remain high throughout the day and night in a typical summer day, ranging from a maximum of 36.5°C to a minimum of 28.5°C. The study also analyses the effectiveness of two basic passive cooling strategies (shading and night ventilation) of 3 sample flats sharing the same orientation, and floor plan but located at different levels within the RTBs. Furthermore, the implications in the seasonal cooling and assessment when considering the adoption of climate-related set-point temperatures (i.e. adaptive comfort approach), beyond the assumed common standard, are also evaluated.

**Keywords:** Building energy performance, Overheating, Passive cooling strategies, Thermal comfort, Retrofit.

## Introduction

The residential building stock represents 30% of the existing building stock in the Turkish Republic of Northern Cyprus (TRNC) (The Department of Social Housing-TRNC (Sosyal Konut Mudurlugu in Turkish) (2015). Problems in mass housing estates in TRNC have been an issue for research with regards to energy policy interventions for many years (ibid). High density of the residential tower block developments and soaring land value in the Mediterranean city of Famagusta have driven residents to maximise liveable spaces by modifying their properties. Simultaneously, as a result of fast rise in population growth and un-planned urbanisation associated with the high-land value and increase in energy consumption leads to the significance of this research in energy efficient retrofit. Studies from the Association of Cyprus Turkish Building Contractors (Kibris Turk Insaat Muteahhitleri Birligi in Turkish) (2016) highlight that strategic consideration for retrofitting the residential building stock would therefore help achieve significant energy efficiency targets. However, the construction

industry lacks strong drivers to implement energy efficient technologies through building construction and retrofit. It is important to note that in this research context, air-conditioning (A/C) units running with electricity are mostly being used for cooling. The Electricity Authority of the TRNC (KIB-TEK - Kibris Turk Elektrik Kurumu in Turkish) in 2016 indicates that residential sector cooling energy use was consumed on 230.367 Mk/Wh in 2003 and this figure rose to 377.971 Mk/Wh in 2015. Given this challenging context, reducing energy consumption of residential buildings particularly in cooling demand can be considered as crucial. The focus of this paper is to investigate the most effective and feasible passive cooling design strategies into retrofitting for energy efficiency and improved indoor thermal comfort.

In this study, an exploratory case study approach is adopted in Famagusta where an existing prototype RTB is explored and analysed according to overheating benchmarks applied on a sample of flats to understand the cooling demand as related to occupants' thermal comfort. This paper is structured as follows; the paper will first discuss the background and justification of research, followed by the hypothesised relationship with regard to the relevant literature. This is then continued with explanations on the methodology employed. Preliminary findings and discussions are given prior to the conclusion.

## **Background and Justification of Research**

### **Location and Climate**

Cyprus, is the third largest island after Sicily and Sardinia. It is located in the Eastern part of the Mediterranean, at latitude 35° North and longitude 33°. According to the Köppen Geiger climate classification, Cyprus has climate characteristics that are typically Mediterranean. The hot and humid summers and wet moderate winters are the main climate characteristics and cause some problems in terms of the demands on energy consumption, because of the requirement for a combination of summer cooling and winter heating. Hence, it also serves to highlight the fact that the prevailing south-west winds are change the relative humidity rate up to 90% along the south coast line in summertime, especially during evening hours. Indeed, it is possible to go so far to as say that this situation affects the thermal comfort conditions of buildings and severely increases the demand for space cooling.

### **Thermal comfort approaches and Building performance**

Many field studies have been conducted in various climates across the world which demonstrate that comfort temperature is closely linked to local climate (Brager & de Dear 1998; McCartney & Nicol 2002; Nicol 2017; Taleghani et al. 2013; Zhang et al. 2017). By following a similar approach, the adaptive thermal comfort theory explains this phenomenon with respect to occupants' active engagement with their indoor environment (de Dear & Brager 1998; Nicol et al. 2012). According to a study by Nicol and colleagues, starting from 2002, an alternative approach to defining comfortable temperatures is the adaptive approach, which stems from the results of a wide range of field studies (McCartney & Nicol, 2002; Nicol & Humphreys, 2002 and Nicol, 2017). From this study, it was found that the thermal expectations of the occupants are related to the outside climatic conditions on a variable basis.

However, it is important to note that there is little information about night-time thermal comfort (CIBSE, 2013). Studies have also shown that sleep deprivation due to overheating during the night is a major motivation for buying domestic cooling appliances. Apart from the most energy efficient building systems and applications, the conventional passive cooling strategies involve shading the transparent elements of the building envelope and ventilating



the spaces effectively during the night-time (Santamouris, 2007). Ferrari et al. (2009) and Zanaotto et al. (2009) studies emphasised the possible implementation of a night cooling strategy during the summer season would have a greater impact on cooling demand when performing dynamic analysis. Studies have also shown the lower air temperature is related to the high daily air-change rate in the monthly average (ibid).

The simulation studies by Ferrari and Zanaotto et al. (2010) asserted that the substitution of the standard set-point with the daily air-change rate could result in a decrease in the discomfort degree-hours calculation. Although not specifically exploring retrofit options, some other studies provide useful references regarding the important role of programmed natural ventilation which can reduce the risk of overheating experienced in RTBs in London (Zahari and Elsharkawy, 2017). Apart from that, starting from these base case studies, cooling demand varies between 10% and 50%, depending on the building orientation and the level of implementation of passive cooling strategies in Famagusta (Ozarisoy and Elsharkawy, 2017). These studies show evidence that the increase of energy consumption related to active cooling of building is a serious environmental danger, and so it is important to increase the number of residential buildings entirely or at least partially relying on passive cooling strategies. However, it should be emphasised that the adaptive comfort standards are a very important mean (Gossauer and Wagner, 2007), which could be adopted in retrofit strategies.

This trend is particularly problematic in the urban context where there is less air movement and urban heat island effects are most noticeable after dusk (Antarikananda et al. 2006; Santamouris et al. 2007 and Suenderman 2015). Consequently, in urban areas of Famagusta, the adoption of globalised housing design standards and inadequate standards for thermal comfort assessment in RTB development projects means that affordable RTBs are planned and designed without climatic considerations resulting in relatively high indoor air temperatures and reduced thermal comfort.

The adaptive approach concerning thermal comfort is currently implemented in the main international standards (EN 1521 2007; ASHRAE 2004). However, the CIBSE Overheating Task Force decided that a new approach to the definition of overheating is necessary, particularly residential buildings without mechanical cooling. This approach follows the methodology and recommendations of BS EN 1521 (BSI, 2007) to determine whether an existing occupied building or a proposed building can be at risk of overheating. Within Famagusta and its urban agglomerations, studies have shown the fact that many RTBs in TRNC currently struggle with overheating and this trend will only become worse with climate change (Ozarisoy & Elsharkawy, 2017).

## **Research Methodology**

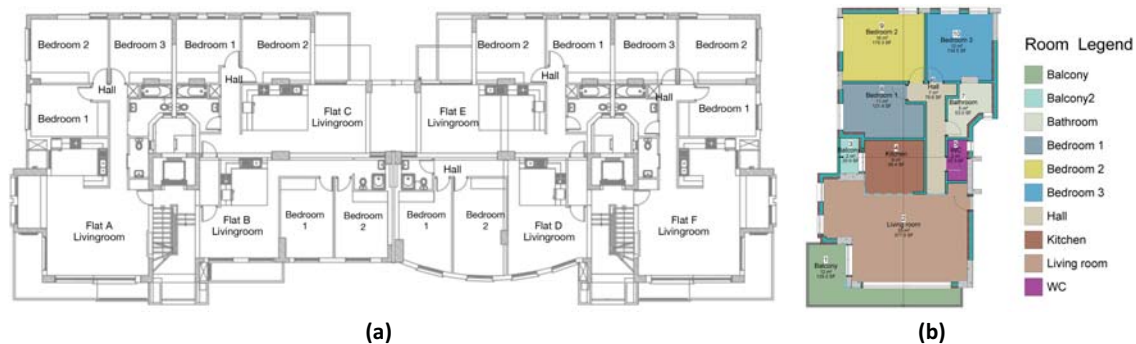
### **Case study: Prototype residential tower block (RTB) as a base case scenario**

The case study for this research is an RTB estate which was designed in 2009 and completed in 2011 (Figure 1 and Figure 2). It is fully managed by a privately-owned construction company and all flats are exclusive when constructed; having lifts, central heating installation and double-glazed windows. It comprises 200 flats over nine 11, 12 & 14 storey towers. In this case study buildings, the existing status shows obvious deterioration of the building envelope, as cracks in the upper floors, damaged concrete balconies, visible signs of moisture in the areas suffering thermal bridges. It is also remarkable to note that there are too many external units for the split-unit air conditioning systems. Even with its specificities, the prototype RTB can be considered as representative of other RTBs in the estate.





**Figure 1.** The current condition of the prototype residential tower block development and the south west facing tower block.



**Figure 2.** The floor plan layout of the prototype residential tower block development and flat type A.

### Research design model

To provide sufficient understanding and analysis of indoor thermal comfort, it was deemed necessary to use a dynamic thermal simulation (DTS) model. The Integrated Environmental Solutions-Virtual Environment (IES-VE) suite was selected as the most appropriate application for this purpose. In terms of validated performance, IES-VE is understood to meet a number of international standards including CIBSE TM 52 and is also accredited for use to European standard BN EN 1521 (IES, 2017).

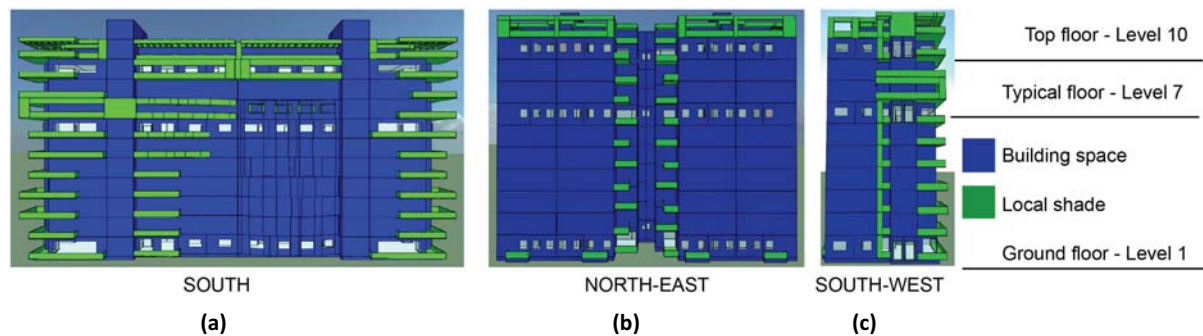
The IES-VE version used throughout was IES-VE 2017.1.0.0. Specifically, the Thermal Comfort add-ins of the IES-VE suite was found to be an application that could offer to measure the ‘adaptive comfort’ of a prototype RTB. It is also of interest to consider in combination with the Dynamic Thermal Simulation (DTS) components of the IES-VE. The model was set up in order to assess the performance of the dwelling under the “worst case scenario” conditions for the south-west facing case study RTB. In this study, profiles were set in the IES-VE application as required for each zone to describe temporal variation in the following: ventilation flow rates, cooling set-point, lighting use and occupancy profiles. Table 1 shows the summary of conditions set up for the base-case model. The performance of the base-case model has been studied with a focus on the risk of overheating.

**Table 1:** Summary of conditions specified for base case model analysis using IES-VE.

Specified Condition	Base-case Model Settings
Simulation Period	1st May – 30th September
Weather Data	Larnaca, Cyprus
Occupants	4 occupants with internal gains of 90W/person/day
Occupancy Patterns	20:00-6:00 working days, occupied all other times
Internal Gains	Gas cooking stove 106 W/m <sup>2</sup> , lighting 8W/m <sup>2</sup>

### Building geometry

The case study RTB is characterised by a rectangular plan (40mx15m) and consists of 11 floors. The ground floor areas are occupied by conditioned spaces (i.e. dwelling units or technical rooms) in order to neglect the variability due to the thermal exchanges to the basement, while all the 10 upper floors are divided into a central distribution space (unconditioned lift and staircases areas) and two side volumes, containing three different floor plan design flats; Type A, B & C as can be seen in Figure 3.



**Figure 3.** The analytical energy simulation model of the tested case study prototype residential tower block.

The rooms and their openings are located on the three different facing facades allowing to appreciate, through only three different plan designs per floor of the model. The performances of the three exposures cover the main orientation cases (North, South and South-West). The simulation outputs can be required also referring to the simulated room zones having the same exposure. Furthermore, the specific results (i.e. each square meter of floor) can be assumed, even in first analysis, for defining the performance of representative flats. Moreover, seven rooms were simulated and evaluated in detail, so that all the possible different performances due to the boundary conditions options were analysed: the first floor, typical floor and top floor south-west facing representative flats.

### Building constructions

To define the building model set, by limiting the number of the variables, the internal structures remain constant – based on the traditional construction materials of the era, hollow brick walls and concrete slabs, while the horizontal envelope components have minor changes depending on the sample flat plan design of the RTB. Hence, the main variation regards the construction materials, building envelope, and involves a window percentage and a construction solution that are representative of likely practices from the newly built RTBs. For this purpose, the building envelope solutions (i.e. shading and ventilation) have been taken into account, with hollow bricks walls and a window surface equal to 1/8 of the floor area, which is a common construction code to provide natural ventilation and lighting. The horizontal components are simple un-insulated concrete and masonry elements. The thermal characteristics of all the considered constructions are summarised in Table 2.

**Table 2:** Thermal characteristics of the construction elements of the prototype RTB.

	S[cm]	U [W/(m <sup>2</sup> K)]	M [kg/m <sup>2</sup> ]	C [kJ/(m <sup>2</sup> K)]
Vertical walls	35.00	0.98	305	264
Roof	36.00	0.91	317	302
Floor	28.50	1.66	303	258
Windows	-	2.91	-	-
Internal floors	28.50	1.63	298	256
Internal walls	11.0	1.57	92	84

### Rationale for the variables for the modelling: undertaken approach for simulation studies

In this work, the effect of passive cooling strategies is simulated according to an adaptive thermal comfort approach, coherent with the likely European standard of BS EN 1521 (BSI, 2007) for retrofitting existing residential buildings, as described below.

### Psychrometric chart and thermal comfort analysis

As previously stated, Famagusta is located in the Eastern periphery of Northern Cyprus, which is known for its hot and humid summer. “CIBSE 2016 Weather files” adopted by Integrated Environmental Solutions (IES-VE) was used to produce the psychrometric chart was climate analysis add-ins of the software automatically interprets the climate variables for a typical meteorological year (TMY) data for the location. So, the software that produces the psychrometric chart can be used to plot the temperature and relative humidity that occurs over the period of 4382 hours CIBSE TM52 weather format climate data of the year. Different design specifications and comfort index parameters are represented by specific zones on the psychrometric chart. The percentage of the hours that fall into different design strategy zones give a relative idea of the optimisation of indoor thermal comfort as shown in Figure 4.

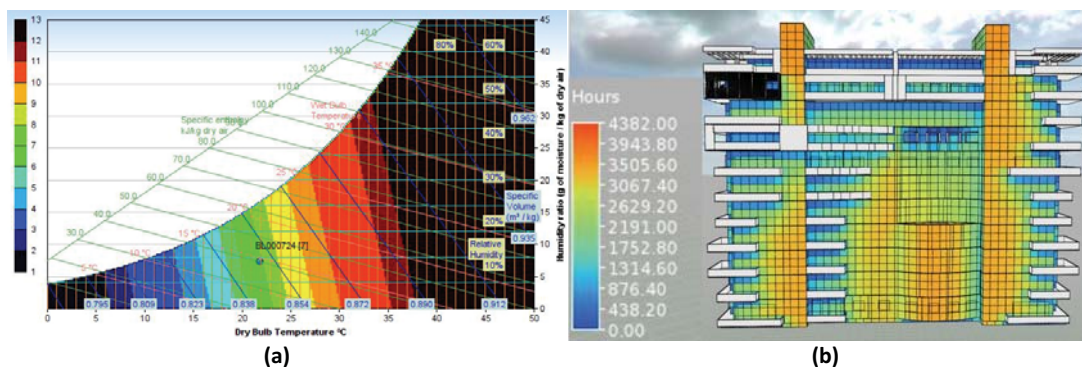


Figure 4. The psychrometric chart for Famagusta and the amount of solar radiation of the prototype residential tower block.

### Passive cooling design strategies into retrofitting: Shading, Night ventilation and Indoor set-point temperature

Firstly, the shading strategy is modelled to consider likely activation of the devices by occupants: therefore, the condition for its application in the simulation software is the amount of solar radiation arriving on the large glazed surfaces, which, in order to take into account the issue of overheating, is set to 100 W/(m<sup>2</sup>K) (IES-VE, 2017). The shading devices, applied to every flat, are external venetian blinds. Within the simulation software, the shading type needs to be represented with a decrease factor of solar heat gains through the windows and with its position both internally and externally, which calibrates the related thermal performance.

Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment and lighting benchmark, night ventilation is modelled between 23:00 and 07:00 during the cooling season in particular only when the indoor operative temperature exceeds the cooling set-point, with an increase in the air-change rate of 0.5 h<sup>-1</sup>, which is recommended as a value that is low but consistent with ventilation rates naturally achievable through single sided openings (CIBSE, 2016).

The comfort requirements from international standards such as EN 15251 (2007) are expressed in terms of operative temperature, the prototype case study RTB set-point regulation is performed according to this value. Therefore, T<sub>op</sub> values of 26°C for cooling,

according to what stated within EN 15251 (2007) for normal level of comfort expectations, are set for the energy need analysis of the prototype RTB. In this regard, since the CEN adaptive method provided in EN 15251 (2007) is valid for outdoor reference temperature up to 30°C, only its running mean temperature equation is considered for this study, which applies up to 33.5°C therefore it is more applicable for the Mediterranean climatic context. The parameters used in the building simulation are summarised in Table 3.

**Table 3:** Building simulation parameters.

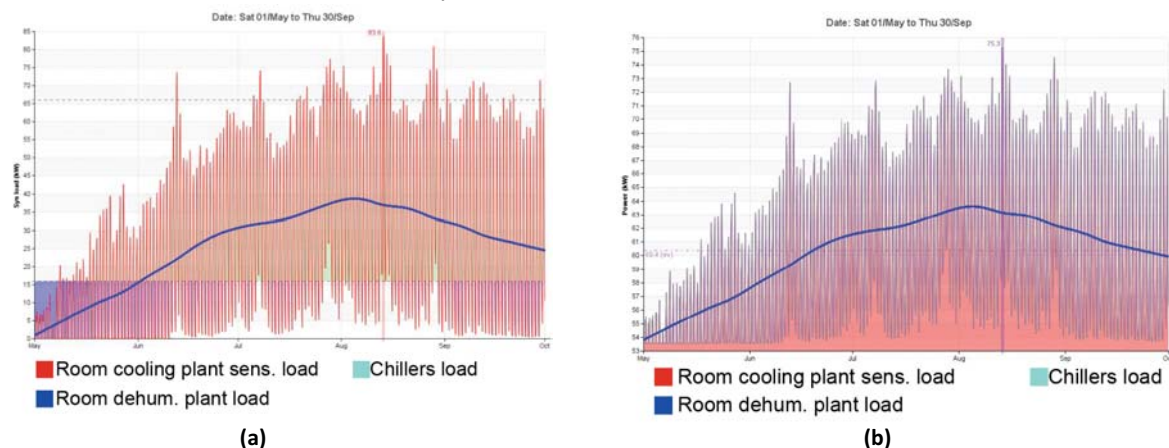
Parameter		Values	
Maximum ventilation rate during days (when $Q_{op} > 23^{\circ}\text{C}$ )		3 [ $\text{h}^{-1}$ ] (from 6am to 23pm)	
Maximum ventilation rate during nights (when $Q_{op} > 23^{\circ}\text{C}$ )		2 [ $\text{h}^{-1}$ ] (from 23pm to 6am)	
		200 [ $\text{W}/(\text{m}^2)$ ] (North, north-east, north-west direction)	
		300 [ $\text{W}/(\text{m}^2)$ ] (All other directions)	
Infiltration	0.1 [ $\text{h}^{-1}$ ]	<b>Cooling set-point (comfort levels)</b>	
Internal heat gains	4 [ $\text{W}/(\text{m}^2)$ ]	Ground floor	24°C
Short wave reflectivity of the façade	0.5 [-]	Typical floor	25°C
		Top floor	26°C

## Results and Discussion: Performance of Base-case Model of Prototype Residential Tower Block (RTB)

The simulations section evaluates the thermal comfort conditions based on the standard CIBSE-TM 52: The limits of thermal comfort: avoiding overheating in European buildings (CIBSE, 2013). The results of the thermal performance of the base-case model were validated according to CIBSE AM11: Building energy and environmental modelling benchmarks including, the BS EN 13779: Ventilation for buildings and BS EN 13786: Dynamic thermal performance for buildings.

### Cooling energy demand

In Figure 5, the cooling energy consumption is shown for the living zones (living room and bedroom 1) on the worst-case (level 10) sample flat. The initial observation is that the flat units greatly exceed the benchmark of 15kW/h. The flat on the typical floor is shown to have worse thermal performance than the one on the first floor. The worst performing flat is the top floor (three exposed external walls) corner flat. The living room in this unit is the worst performing zone with a performance that exceeds the benchmark by over eight times at a value of 83.6 kW/h. It is worth noting that the bedroom 1 exceeds the benchmark by over seven times with a value of 75.3 kW/h.



**Figure 5.** The calibrated existing cooling energy consumption of the worst case top floor units' living room and bedroom 1 during the pre-retrofitting phase.



## Evaluation of overheating assessment

This criterion was assessed by the total number of days in a calendar year where the exceeds 6°C<sub>h</sub> while that zone was occupied (CIBSE, 2013). As previously stated in the literature, in compliance with criterion 2, a zone should exceed this value for no days (ibid). The results for the base case are shown in Table 4. As with criterion 1, the sample flat units are shown to exceed the benchmark with the corresponding top floor flat unit showing the greatest level of overheating. Within this flat unit the living room surpasses 6°C<sub>h</sub> for 105 days and the bedroom 1 surpasses 6°C<sub>h</sub> for 87 days out of 153 days respectively. This indicates that the zones within the flat struggle with a large percentage of time at very uncomfortable thermal conditions throughout the year. For TM 52 Criteria III, the highest values of  $\Delta T$  are shown, with all simulated rooms in the ground, typical and top floor flats failed to pass the criteria. In all of these sample flats, bedroom 1 performs the highest peak  $\Delta T$  with a value of 10°C due to its north facing orientation.

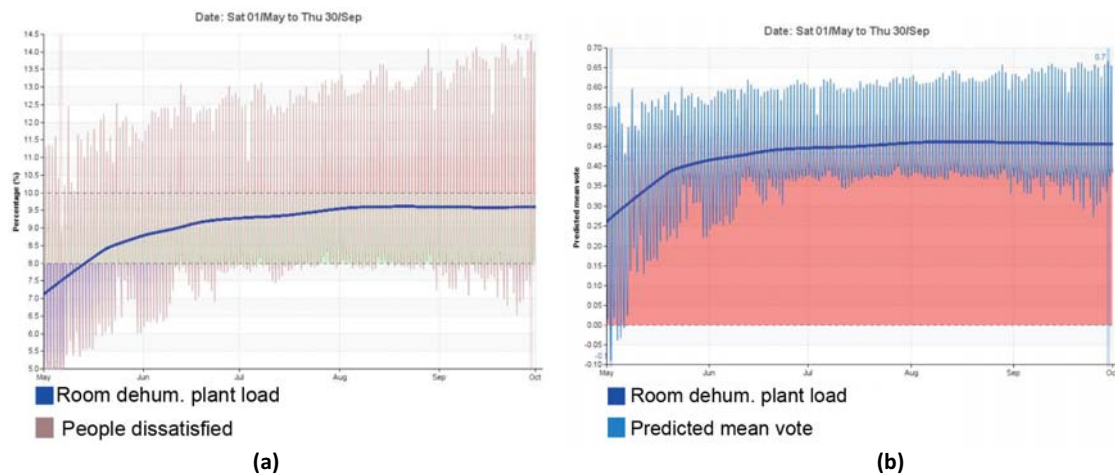
**Table 4:** Results for TM 52 Criteria II and III for study year ( $\Delta T$  is room temp. minus maximum adaptive temperature)

Flat	Livingroom	Bedroom 1	Bedroom 2	Bedroom 3
<b>TM52 Criteria II Daily weighted exceedance (°C<sub>h</sub>)</b>				
<b>Ground Floor</b>	51	45	43	37
<b>Typical Floor</b>	60	48	62	69
<b>Top Floor</b>	60	47	61	69
<b>TM52 Criteria III Max. <math>\Delta T</math> (°C)</b>				
<b>Ground Floor</b>	5	5	4	4
<b>Typical Floor</b>	8	9	7	8
<b>Top Floor</b>	11	10	7	8

The flat on the typical floor is again found to perform better than the one on the top floor. The living room is observed to be the critical zone within the sample flats as it fails criterion 3. The differentiation in the performance of the flat on the first floor is attributed to the location of rooms. The unit with three exposed walls has reasonably reduced capacity for providing thermal comfort within the adaptive comfort limits. The living room in first floor flat unit and top floor exceed what 4°C by 4 hours and 9 hours annually, respectively.

Figure 7 illustrates that the zones under consideration within the case study RTB's sample flat units are found to exceed the acceptable limits of the CIBSE TM 52 criteria (both PPD and PMV). The least performing space is the living room as it incorporates the internal heat gains from the open plan kitchen design. The flat unit with poorer ventilation performance was shown to be flat 3 on the top and ground floor (flat 1). This is attributed to the opening ratios and material properties of the double-glazed windows. These flat units are constructed with three exposed external walls allowing for a higher rate of heat transfer.

Figure 6 summarises the overall cooling demand reductions are connected to the introduction of the variable set-point in summer are shown for all three representative sample flats. The results point out that during the cooling season, the cases reveal significant differences based on the adaptive set-point of the heavy weight construction materials, in particular for this base case model RTB, which is not provided with any insulation layer. Furthermore, it is important to highlight the fact that comparing base case and retrofitted case, the reduction in the cooling need assesses for the heavy weight constructions tend to decrease as the height of the floor level and orientation of the flat, while in case of implementation of passive strategies into retrofitting the trend is inverse.



**Figure 6.** The overall results of the Predicted People Discomfort (PPD) and Predicted Mean Vote (PMV) of the base case prototype retrofit tower block.

It is important to highlight that, in terms of criterion 3, the bedrooms in each of the tested flat units also show exceedance of 4°C during the simulated summer period. This can be attributed to the classification of the bedrooms as a “night zone” which means it is only occupied at night. This means that the external night time temperature rises above a certain point whereby the addition of internal gains from occupants is significant enough to raise the temperature above  $T_{upp}$ . The results also indicate, in comparison, the living room is either partially or fully occupied at all times. This incorporates those periods where external daytime temperatures reach their maximum.

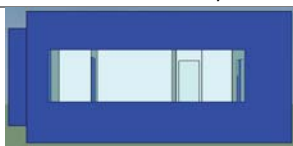
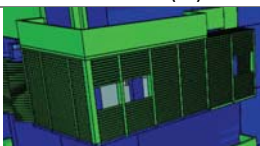
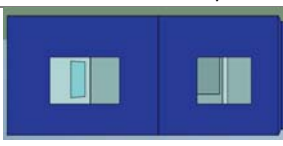
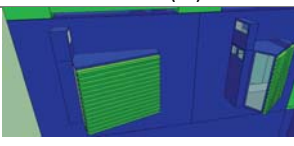

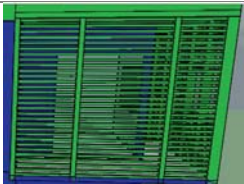
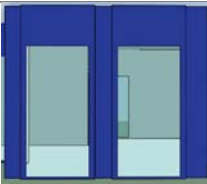

#### Passive cooling design strategies into retrofitting

The simulated and tested passive cooling design strategies are shown in Table 5 and 6. From the analysis, it can be seen that once again the passive shading strategies are the ones characterised by a stronger daily temperature variance, also due to the large glazed surface (which is not shaded in this case).

**Table 5:** Studied scenarios.

Scenario	Description
1	Base case with cross ventilation and shading
2	With external shading (50% Transparency) and without cross ventilation
3	Cross ventilation by providing opening between existing openings and implemented windcatchers

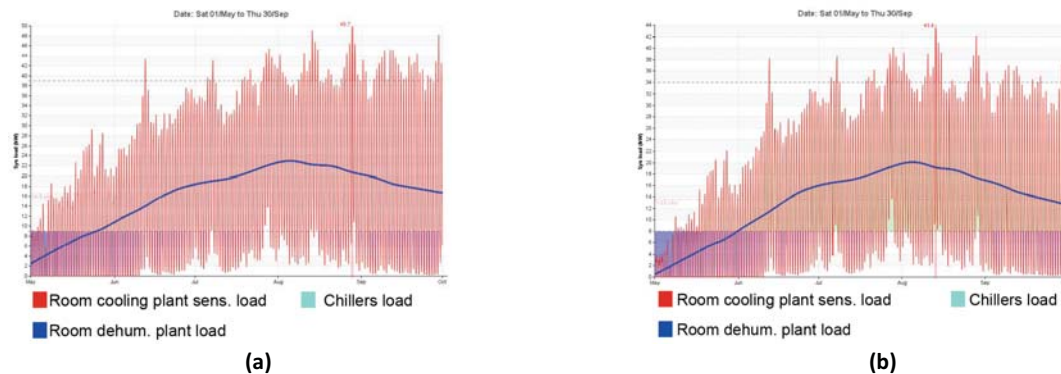
**Table 6:** Characteristics of the glazed surfaces for the different solutions.

Pre-retrofit	Post-retrofit	Pre-retrofit	Post-retrofit
Glazing type: Type A	U-value: 0.298 W/(m <sup>2</sup> K)	Glazing type: Type C	U-value: 0.299 W/(m <sup>2</sup> K)
Dimension: 460x120h/cm	Thickness: 0.480 (m)	Dimension: 140x120h/cm	Thickness: 0.365 (m)
			
Glazing type: Type B	U-value: 0.298 W/(m <sup>2</sup> K)	Glazing type: Type D	U-value: 0.312 W/(m <sup>2</sup> K)
Dimension: 190x230h/cm	Thickness: 0.400 (m)	Dimension: 110x230h/cm	Thickness: 0.125
			

\*Corrected U-values determination according to the nominal U-values during the simulation.



According to the results of the dynamic thermal simulation, energy savings of around 46% are expected, with the main goal of the study to save 50%. As could be expected in a residential building located in a hot and humid climate zone of the study context, for the non-retrofitted case the cooling and heating (73%) comprise the biggest part of the total energy consumption (Ozarisoy and Elsharkawy, 2017). Figure 7 summarises the results of the proposed changes done in the model, the cooling consumption decreases 52% by implementing passive shading devices (exterior venetian blinds and internally operable ventilation openings); therefore a 30% reduction of cooling load for the prototype case building is also achievable by improving the building envelope (new U-value  $0.15 \text{ W/m}^2\text{K}$ ), by considering fitting external cladding with good thermal mass characteristics (Ozarisoy and Elsharkawy et al., 2017).



**Figure 7.** The calibrated existing cooling energy consumption of the worst case top floor units' living room and bedroom 1 during the post-retrofitting phase.

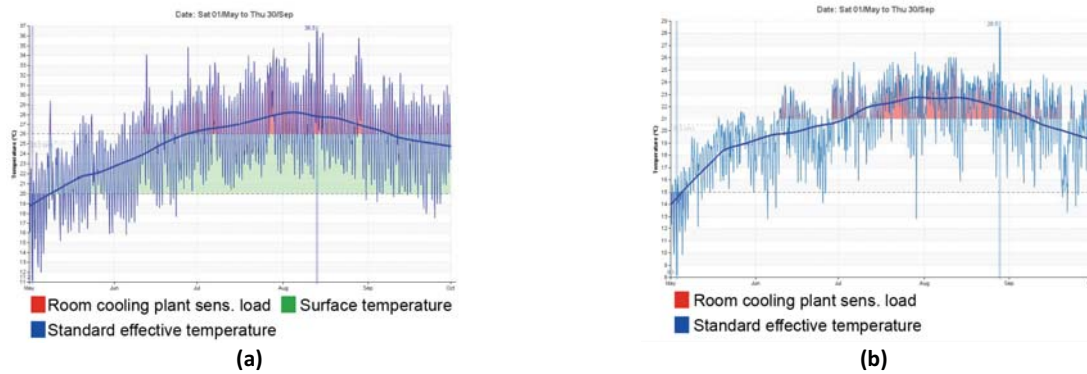
Specifically, in this case thermal bridges play an important role in energy consumption. One of the main objectives of the intervention is to be minimise their impact. As thermal bridges are not calculated correctly in dynamic simulations, in this case they have not been taken into account, knowing that, due to this factor, natural ventilation and air infiltration rate are major input parameters for calculating cooling demand. Results of the energy balance in more detail can be seen in Table 7. It is remarkable to note that the most important energy savings are due to changes developed in the natural ventilation through implementation of the internally operable ventilation opening systems on the building envelope.

**Table 7:** Energy consumption during the pre and post retrofitting.

	Pre-retrofit	Post-retrofit
Cooling ( $\text{kWh/m}^2\text{-year}$ )	58.7	13.1
Lighting ( $\text{kWh/m}^2\text{-year}$ )	29.3	25.4
Equipment ( $\text{kWh/m}^2\text{-year}$ )	14.2	14.2
<b>TOTAL (<math>\text{kWh/m}^2\text{-year}</math>)</b>	<b>102.2</b>	<b>52.7</b>

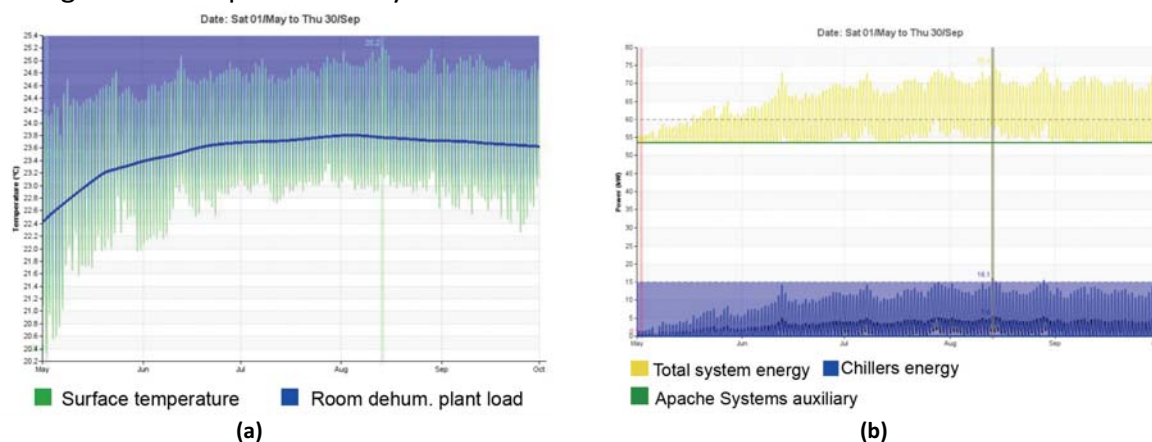
## Findings

The cooling need trends are reported in Figure 8, one based on the conventional set-point and the other based on the adaptive comfort model; by comparing them, the different magnitude of cooling need assessment depending on the considered approach can be strongly appreciated, since the desired adaptive temperature in the worst-case scenario is significantly higher than  $26^\circ\text{C}$ . All three simulated and tested sample flats show the higher indoor air temperatures, during the occupied hours of the day because of the direct solar radiation through the unshaded large-glazed windows. The flat unit in the top floor at level 10, among the ground floor (level 1) and typical floor (level 7), has higher loads during the occupied hours, since it cannot release all the heat gained and stored during the day and during the night-time.



**Figure 8.** Distribution of air temperature during the pre and post retrofitting phases in the worst –case scenario top floor flat.

Figure 8(b) shows the summer operative temperature trends in the retrofitted flat units and the cooling load related to the two set-point options, when external venetian blinds are used as a shading device. Figure 9 shows the summer operative temperature trends in the worst case top floor flat unit at level 10 when night ventilation is adopted as a free cooling strategy. The daily average temperature decreases and the daily variability increases due to the cooler conditions during the night-time, but the most important remark regards the fact that the behaviour of the wind catcher systems to become more similar to the passive design principles. This is due to the fact that night ventilation allows the internal mass to lose heat during the unoccupied hours by natural ventilation.



**Figure 9.** Distribution of air temperature and cooling energy consumption of the worst case top floor flat by implementing wind catcher systems for cross ventilation strategy.

Additionally, starting from these base case studies, when the adaptive set-point is used, the decrease in the cooling need due to the additional ventilation is required, in particular for the heavier construction materials and its systems. This is due to the strong effect of heat loss from the heavy weight structures caused by additional discharge rate during the night-time. This is because, the adaptive indices have been developed according to the occupants' thermal sensations and preferences (Nicol, Humphreys and Roaf, 2012; Ferrari and Zanolto, 2012 and Nicol, 2017). In this study, the adaptive comfort temperature represents the climatization system set-point as autonomously managed by the occupants, according to the external climatic conditions. This is due to the fact that it takes into account a cooling need assessment quite respect the one referred to the implementation of passive cooling design strategies into retrofitting.

## Conclusion

This paper aimed to evaluate the risk of overheating and potential ways to overcome this through the implementation of passive cooling design strategies (i.e. shading and natural ventilation) of a tower block in Famagusta, Northern Cyprus. When testing the base-case model, the top floor flat on level 10 has the worst thermal performance because of its proximity to the un-insulated roof, the effect of hot air movement into the space and the structural thermal behaviour characteristics of the RTB's envelope. It can be observed that there is a lack of diurnal temperature variation within the sample flat units which means the internal operative temperatures remain relatively high throughout the day and night, ranging from a maximum 36.5°C to a minimum of 28.5°C. This is not significant enough to induce night cooling. The external fabric; un-insulated roof and three exposed walls are a key determinant factor due to its high U-value, the surface area and the level of exposure to solar gains. This induces a high heat transmittance into and out of the top floor flats which has a significant effect on the operative temperatures of those flats.

Overheating is likely to occur at a frequent rate in the top floor flat's bedroom 2 and 3 than the living area. It can be seen that over 7% of the hours rose above the 28°C and the BS EN 1521 Category II upper limit when calibrated temperatures are evaluated in the living area using the CIBSE and the adaptive thermal comfort models. Respectively, high summertime temperatures (18% of the hours above the 26°C indicator) and warm discomfort (15% of the hours above the BS EN 1521 Category II upper limit) are also reported both in the bedroom 2 and 3. Finally, this study elucidates the potential applicability of passive cooling strategies to optimise thermal comfort at the worst-case top floor flat in peak summer. The findings show that the cooling consumption decreases by 52% by implementing passive design strategies (exterior venetian blinds and wind catcher systems). From this study, it appears the passive design principles would be energy-efficient and cost-effective for retrofitting RTB. This is a crucial finding that needs to be investigated in further research to assess and optimise risk of overheating and understand occupants' thermal comfort when enhancing "night cooling" effects in RTBs in this Mediterranean climate.

## References

- British Standards Institution [BSI]. (2007). BS EN 15251: 2007: Indoor Environmental Input Parameters for Design and Assessment of Energy Performance of Buildings Addressing Indoor Air Quality, Thermal Environment, Lighting and Acoustics; BSI: London, UK, 2007.
- CIBSE (2016). Environmental Design, CIBSE Guide A. London, UK: Chartered Institution of Building Services.
- Ferrari, S. & Zanotto, V. (2009). EPBD and ventilation requirements: uneven inputs and results in European countries, in Proceedings of the 30th AIVC Conference – Trends in High Performance Building and the Role of Ventilation, Berlin, 1-2 OCT 2009.
- Integrated Environmental Solutions (IES). (2017). IES Software Validation. Available at: <http://www.iesve.com/software/software-validation> (Accessed 14 September 2017).
- Kottek, M., Greieser, J., Beck, C., Rudolf, B. & Rubel, F. (2006). World Map of the Köppen Geiger climate classification updated. *Meteorology.Z.*, 15, 259N263. DOI: 10.1127/0941N2948/2006/0130.
- Nicol, F., Humphreys, M. & Roaf, S. (2012). *Adaptive Thermal Comfort: Principles and Practice*, Routledge, Taylor and Francis Group.
- Nicol, F. (2017). Temperature and adaptive comfort in heated, cooled and free-running dwellings. *Building Research & Information*, pp.1–15.
- Ozarisoy, B. & Elsharkawy, H. (2017). Retrofit Strategies for the Existing Residential Tower Blocks in Northern Cyprus. Passive and Low Energy Architecture (PLEA) Conference, Edinburgh, Scotland.
- Santamouris, M.; Pavlou, K.; Synnefa, A.; Niachou, K.; Kolokotsa, D. (2007). Recent progress on passive cooling techniques Advanced technological developments to improve survivability levels in low-income households. *Energy Build.* 39, 859–866.
- State Planning Organisation—TRNC (Devlet Planlama Orgutu—KKTC). Economic and Social Indicators Statistics. (2015). Available online: <http://www.devplan.org/Frame-eng.html> (accessed on 8 August 2017).
- Zahiri, S. & Elsharkawy, H. (2017). Building Performance Evaluation for the Retrofit of Council Housing in the UK: A case study of a tower block in London, Passive and Low Energy Architecture (PLEA) Conference, Edinburgh, Scotland.

# An innovative energy efficiency application development: through the evaluation of occupants' behavioural issues and its impact on domestic energy consumption in the UK

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**Abstract:** The research investigates the reason why low-carbon retrofit programmes always may not meet expectations. It is explored by focusing on a series of 'hard-to-quantify' factors, especially the energy-related behaviours and their impact on energy performance. The research assumes that the abovementioned parameters have not been thoroughly taken into consideration for optimising domestic energy performance. This is also the cause of the phenomena of 'Building Performance Gap (BPG)'. To cope with this issue, the correlations between occupants' behaviours and energy performance are investigated by adopting a mixed research methodology where questionnaire survey and the review of energy efficiency tools were carried concurrently to collect and analyse quantitative and qualitative data. The data collected is mainly quantitative but supplemented by qualitative data from a few open questions and in-depth interviews. This paper primarily focuses on the research survey design and how the required data was collected and analysed to help achieve the research aim. The preliminary data analysis was also presented in order to draw a general picture of the conditions of social housing in London. The issues encountered during the distribution of the questionnaire were also discussed in order to inform relevant future studies. At the end, the found correlations could help to form an innovative smart phone application in order to adjust occupants' energy-related behaviours and provide incentives in taking up the low-carbon retrofit projects. Thus, reducing the BPG and increase energy efficiency in the UK housing sector.

**Keywords:** domestic building, home energy performance, occupants' behaviour, questionnaire survey, energy efficiency application

## Introduction

The reasons of climate change are diverse and over-consumption of energy generated from burning fossil fuels is considered one of the major causes (Liu et al, 2016). The importance of reducing CO<sub>2</sub> emissions has been realised for a few decades. Governments establish energy policies and protocols to regulate energy consumptions in different sectors. In Kyoto Protocol, UK agreed to achieve 12.5 per cent CO<sub>2</sub> reduction by 2010 comparing to its emissions in 1990 (United Nations, 1992). In the domestic level, UK also sets out a 15 per cent energy reduction rate by implementing renewable technologies by 2020. Besides, a further CO<sub>2</sub> reduction of 80 per cent compared with 1990's level was also vowed by the UK government by 2050 (UK Renewable Energy Roadmap, 2013).

Residential sector, as one of the primary energy consumers (almost 30 per cent of the total energy), is in focus by the UK government. A recent report (Environmental Change Institute, 2005) demonstrates that the growth of energy demands in the residential sector has been much higher than other sectors between 1990 and 2003. In addition, housing energy demands have increased by 32 per cent since 1970 mainly deriving from heating which makes up 60 per cent of overall energy consumptions.

The research focuses on increasing the efficiency of low-carbon retrofit in existing UK homes. A number of case studies were examined in this paper. Besides, occupants' socio-economic characteristics, energy consumption behaviours and their impacts on energy performance were also investigated. In a further step, the study attempts to consolidate the role of smart metering devices, and technology towards occupants' energy-related

behaviours, thus regulate these behaviours by designing an innovative smart phone application at energy end-users' level.

### **Research context: Low-carbon retrofit and occupants' behaviour**

In order to meet the CO<sub>2</sub> emission reduction target (80 per cent) by 2050 (Climate Change Act, 2008), the UK government has tightened its energy regulations to pace up the progress (DCLG, 2013a). As stated by Dowson et al (2012), policies were also released to increase the incentive of taking up low-carbon retrofit programmes such as the Feed-in Tariff (Fit), the Green Deal, the Renewable Heat Incentive (RHI), the Decent Homes, etc. The past and current retrofit projects have been assessed with their success and falls. Several research studies suggest that retrofit projects need to be widely spread to be efficient and effective (Webber et al., 2015; Smith and Swan, 2012). Besides, occupants' socio-economic factors need to be taken into consideration (Ma et al, 2012). In a few cases, the retrofit works were criticised for the lack of quality which may lead to the failure of the project (Gilbertson et al., 2008; Long et al., 2014; LDA, London Councils et al., 2010, 2011 and 2014; TSB, 2014). The case studies adopted in this research are either currently under retrofit constructions or expected to be retrofitted in the future. The review of the previous retrofit case studies will help to well understand the government's 'top-down' retrofit approach. Abovementioned issues are also focused and investigated in this case study during the research.

Notably, domestic energy performance is also subject to how occupants operate their homes, especially the heating control systems. So a wider range of 'hard-to-quantify' variables will affect energy performances such as occupants' socio-economic and behavioural aspects (Greening et al., 2000; Khazzoom, 1980; Saunders, 1992). The Building Performance Gap (BPG) stands for the differences of domestic energy performance between design and as-built. The detailed explanation was also demonstrated by Sunikka-Blank and Galvin (2016) that the BPG includes two types: the 'prebound effect' where designed energy performances is more than as-built performances and the 'rebound effect' where occupants use more energy than expectations. In order to avoid the 'rebound effect', the 'hard-to-quantify' factors need to be taken into consideration in diverse approaches to try and draw helpful correlations for reducing energy consumption (Sorrell and Dimitropoulos, 2008; Hadjri and Crozier, 2009; Preiser et al., 1988; Zimring and Reizenstein, 1980; Chiu et al., 2004). Suggestions are also given in some recent reports (LDA, London Councils et al., 2010, 2011 and 2014; TSB, 2012 and 2014) on how to regulate occupants' behaviour for more efficient energy consumptions, such as the introduction of smart meters/IHDs and stronger interaction between construction team, professionals and the occupants.

### ***Energy efficiency tools and applications in the domestic sector***

In the UK, the transition of energy network is currently taking place where Advanced Metering Infrastructure (AMI) is widely adopted. Smart meters and In-House Displays (IHDs) in each home help energy end-users effectively understand, appreciate and manage their energy consumptions (The Cabinet Office et al, 2011). Through different case studies, researchers who affirm the positive role of AMI and smart meters include Gans et al (2013), Stromback et al (2011), Wesley Schultz et al (2015) and Zhang et al (2016). The installation of pre-payment meters helped to reduce 11 to 17 per cent of electricity consumption in an experimental large scale case study (Gans et al, 2013). Recent report (Stormback et al, 2011) also indicates a 5.13 to 8.68 per cent energy consumption reduction among 100 pilots in Europe. However, it was also proven inefficient in some of the case studies (Rajagopalan et al., 2011; Schultz et al.,



2015; Carroll et al., 2014; Hargreaves et al., 2017) due to privacy invasion and the extra energy consumptions on AMI and smart meters. In detail, occupants' personal energy data, and even their habits and energy use signatures will be unintendedly published (McDaniel, 2009). Furthermore, a number of scholars (Schultz et al, 2015; Carroll et al, 2014; Hargreaves et al, 2017) suggested not only rely on smart meters and IHDs but also carrying out occupant trainings and close interactions with them as the combined approaches to achieve energy efficiency.

Although some of the occupants' socio-economic and behavioural aspects are unquantifiable parameters (Sunikka-Blank and Galvin, 2016), the correlations of these factors and energy performance can be analysed and demonstrated in equations. The found implications could be one of the important components of the future energy management system and act as an energy efficiency application in the smart phones. In addition, energy efficiency applications are developed based on the smart metering devices to help occupants understand their energy consumption patterns and save energy effectively (Zhang et al, 2016). As energy companies are responsible for the roll-out of smart meters, they developed energy efficiency apps for their own customers such as British Gas app, EDF Energy app and E.ON app (British Gas, 2017; EDF Energy, 2017, E.ON UK, 2017, Npower, 2017, and Scottish Power, 2017). Energy providers' applications all tend to provide easy and convenient customer experiences, thus have similar functions and aspects. Apart from that, applications developed by European and International specialised companies also include efergy engage, OVO and Homeselfe (OVO Energy, 2017; apkpure, 2017; efergy engage, 2017 and Homeselfe, 2017). A comprehensive comparison of abovementioned applications was carried out by Shi et al (2017) that applications developed by specialised companies are more innovative than the ones developed by major energy providers in the UK as more interesting aspects are found from them, such as 'retrofit comparison scenarios', 'behavioural suggestions' and 'energy performance mock-ups'. Although the more innovative and advanced aspects in applications are significantly recognized (Barrett, 2016), they have not been widely implemented and incorporated into the existing energy management systems.

### **Research methodology and survey design**

The research asserts that a series of 'hard-to-quantify' factors, especially occupants' behavioural issues, have not been thoroughly considered for home energy performance. Thus, the correlations between those factors and home energy performance need to be investigated by employing a mixed research design where questionnaire survey and review of energy efficiency tools were carried out concurrently. Data collected will be mainly quantitative but supplemented by qualitative data from several open questions and in-depth interviews. Then Statistical Package for the Social Sciences (SPSS) is employed to find the potential correlations. On the other hand, the review of the energy efficiency tools has been performed to inform the design of the innovative smart phone application. The purpose of designing the questionnaire is to effectively extract data from respondents (Hague, 2006). It aims to prevent the questions being asked in a random way by keeping a structured, systematic order of questions. The design of the questionnaire also needs to ensure that the data is processable and with minimal or no errors (Dornyei, 2003).

The questionnaire aimed to collect participants' attitudes towards low-carbon retrofits, as well as household profiles and their lifestyle patterns. It also aimed to gather a wide range of necessary information from the participants for the later data analysis, such as their housing conditions, energy use patterns, energy-related behaviours, energy conservation



awareness, and occupants' attitude on energy efficiency application. The majority of the questions were designed with dichotomous, multiple choices and rank order scaling questions. In the condition of acquiring sufficient information, these questions are easy to be processed in the next stage of data analysis. However, in order to get more comprehensive data, open-ended questions were also asked so as to probe into more details (Mathers et al, 2009). The questionnaire is divided into four sections in order to capture different types of required information. To understand the housing conditions, structured questions was designed to record and understand basic conditions of the dwellings including room numbers, room types, building services, walls, roofs, materials of openings and any damaged and issues occupants have experienced. Household profiles were also asked in the questionnaire with structured questions to collect demographical data. In addition, the semi-structured questionnaires were developed in order to understand the occupants' attitude and awareness towards low-carbon retrofit and their behavioural preferences. For example, occupants were asked to explain if they have changed their energy suppliers or energy plans. They were also asked to write the reason if they do not open extractor fans when take the shower which is an effective way to improve indoor environment quality. Besides, occupants were asked if they think they have used more energy than they should and why.

### **Data collection and analysis**

The data collection was carried out in the manner of door-to-door questionnaire distribution. The collected data were then analysed to investigate the potential correlations between socio-economic/behavioural factors and home energy performances. Questionnaire distribution has been completed by August, 2017 targeting two social housing estates in the Borough of Newham. The data analysis is currently ongoing. The consequent sections explain the recent data analysis and demonstrate a few initial key inferences.

### ***Distribution of questionnaires***

Both of the target estates was built as an affordable housing with low rents for the people who are struggling with their housing costs. The first estate is currently under refurbishment that was carried out by the appointed contractor. The project is aimed to deliver energy-efficient insulations internally and externally in two phases. The first phase of the refurbishment focusing on the interior has been completed by the end of 2016. The second phase of the work focusing on exterior insulations has been started and expected to be completed by the end of 2017. The block does not have a basement floor but a roof terrace. The occupants in the tower block are suffering certain degrees of issues such as damp, cold, draught and condensation. The second estate was built by 1967 with 23 storeys. Externally, the estate is clad in asbestos cement panels painted various shades of blue. For healthy and safety purposes, the external panels of the tower block were jet washed in 2012 which has taken away the original paint finishes and part of the construction sealing. The problems occurred has been aware by the Council and the planned improvement work is on schedule.

The data collection process started in April, 2017 and was completed in August, 2017. Two housing estates in the Borough of Newham were taken as the research samples for the roll-out of questionnaires. The research started with the first estate with forty-four flats during the first 2 months of the investigation and then continued with the second one with one hundred and nine flats during the following months. From the first housing estate, 18 flats have completed and returned the questionnaires while 32 flats have completed and

returned questionnaires from the second estate. The research findings based on the collected data are presented as below.

Based on the records presented above, the response rates of the questionnaires between the two estates are different. A few internal and external factors affecting occupants' willingness of collaboration were identified and discussed as below. Besides, lessons learnt and potential improvement for future questionnaire distribution approaches are also noted.

The response rate at the first estate is 40.9 per cent which is much higher than the second estate (29.4 per cent). There are a few aspects proving that occupants at the first estate are more cooperative than the second estate: their social, economic and personal issues determine whether or not the researcher can have an opportunity to speak to them and also determine the difficulties of convincing them taking up the survey. In detail, households with more full-time employed family members tend to spend less time at home, especially in the day time. So the researcher has less opportunity to meet them in person. Besides, occupants with different cultures and religions may not like to open their door and speak to the strangers, especially male researchers. In addition, according to the conversations with households and local staffs, there are many disabled and occupants in need of care living at the second estate. That also increases the difficulties of completing the questionnaires. The external factor that impact on the response rate is the cooperation of on-site contractor. It is a driving factor that leads to a high responding rate at the first estate. As mentioned previously, the refurbishment work was being undertaken on-site at the time of questionnaire distribution so the contractor has been able to keep a close relationship with all local occupants. Coffee meetings were held regularly to receive feedback from occupants and provide them with updates concerning the latest construction progress. Besides, as the research was carried out in parallel with the construction work, occupants tended to be more cooperative due to the word-of-mouth dissemination about the research undertaken.

### ***The one-way data analysis***

The questionnaire is separated into four sections exploring the issues affecting home energy performance, such as housing conditions, energy use patterns and behaviours, energy efficiency applications, and occupants' socio-economic characteristics. A review of the initial data analysis is hereby presented with the details of some key findings.

#### ***Quarterly electricity and gas bills***

Occupants are also asked to provide their quarterly electricity and gas bills in the questionnaires. It is found that each household uses almost the same amount of electric and gas. In general, households' gas bills may slightly higher due to high gas demands in the winter.

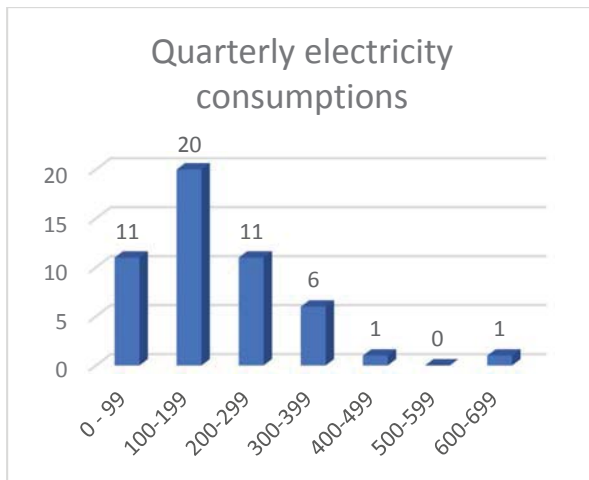


Figure 1. quarterly electricity bills

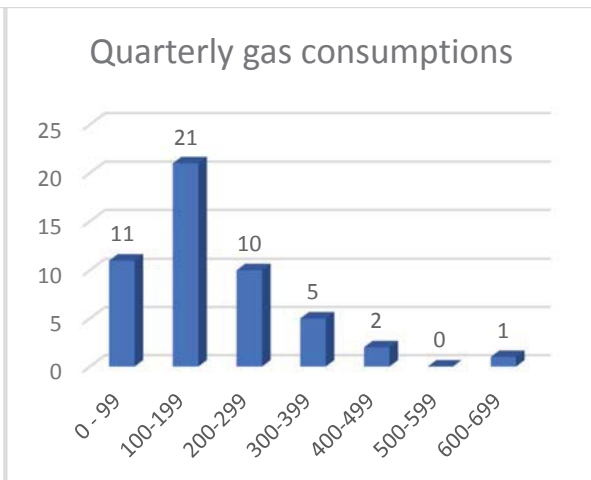


Figure 2. quarterly gas bills

Among the participants, 22 per cent of them have their quarterly electricity bills within £0-£99; 40 per cent of the households pay their quarterly electricity bills within £100-£199; 22 per cent of the households' quarterly electricity bills are within £200-£299; 12 per cent of them spend £300-£399 on their quarterly electricity bills; 2 per cent of their quarterly electricity bill are within £400-£499; and another 2 per cent of them pay their quarterly electricity bills between £600-£699. From the results, 62 per cent of the participants tend to spend less than £199 for their quarterly electricity bills and only 16 per cent of them tend to spend more than £300 for their electricity bills.

*Have the occupants changed their energy supplier/energy plans?*

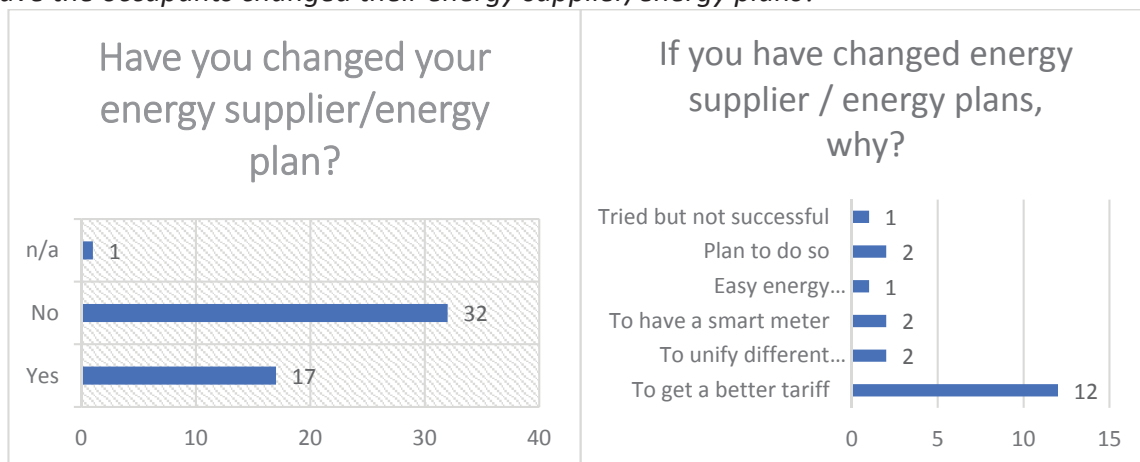


Figure 3. Have you changed your energy supplier/energy plan? If yes, why?

According to Figure 3, the 64 per cent of the respondents have not considered changing energy suppliers or plans. 4 per cent of them expressed that they are wishing to do it but have not started yet. Among the respondents who have changed their energy plans or energy suppliers, 60 per cent of them changed their energy plans or energy suppliers for better tariffs; 34 per cent of them did it for easy energy management or installation of smart meters; 6 per cent of the occupants were either plan to do it or have tried but not successful. Undoubtedly, financial savings is the dominating reason for occupants to make changes. This means that any financial savings in energy bills will probably be considered and appreciated.

*The heating controls*

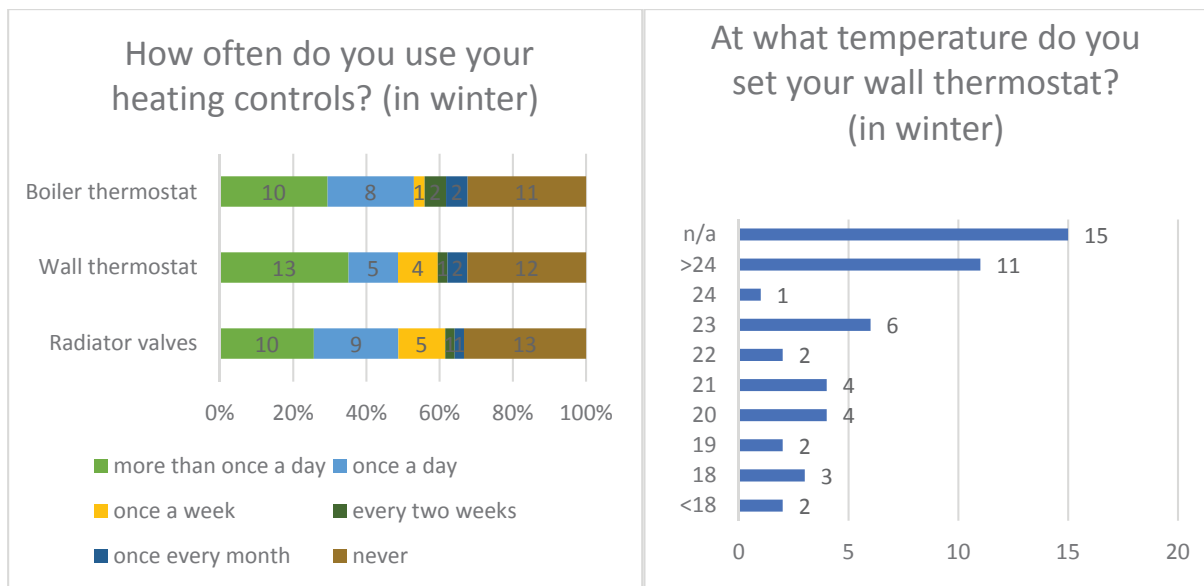


Figure 4. how often do you use your heating controls? Figure 5. What temperature do you set thermostat? Occupants were also asked to provide the information of how frequently they use the heating controls at their homes. As a result, 52.9 per cent of the households use their boiler thermostat at least 'once a day'; 48.6 per cent of the participant will use their wall thermostat at least 'once a day'; and 48.7 per cent of them use radiator valves at least 'once a day'. On the other hand, 51.4 per cent of the participants will only use wall thermostat at most 'once a week'; 51.3 per cent of them will use radiator valves at most 'once a week'; and 47.1 per cent of the households use boiler thermostat at most 'once a week'. In general, around 50 per cent of respondents use their controls at least once a day, which may imply that they appreciate the significance of those controls perhaps for comfort reasons or to keep their bills down.

According to Figure 5, the temperature occupants set their wall thermostat demonstrates that occupants tend to set their wall thermostat higher in order to have a more comfortable living environment. The majority of the occupants (78.0 per cent) tended to set their wall thermostat more than 21 °C which may not be necessary and encounter the cardiovascular risk when the indoor temperature is more than 24 °C (OVO Energy, 2017). Recent reports (Gram-Hanssen, 2014) also states that the main causes of high heat consumption are indoor temperatures, extensive ventilation and hot water over-consumption.

#### *Energy related behaviours and preferred smart application aspects*

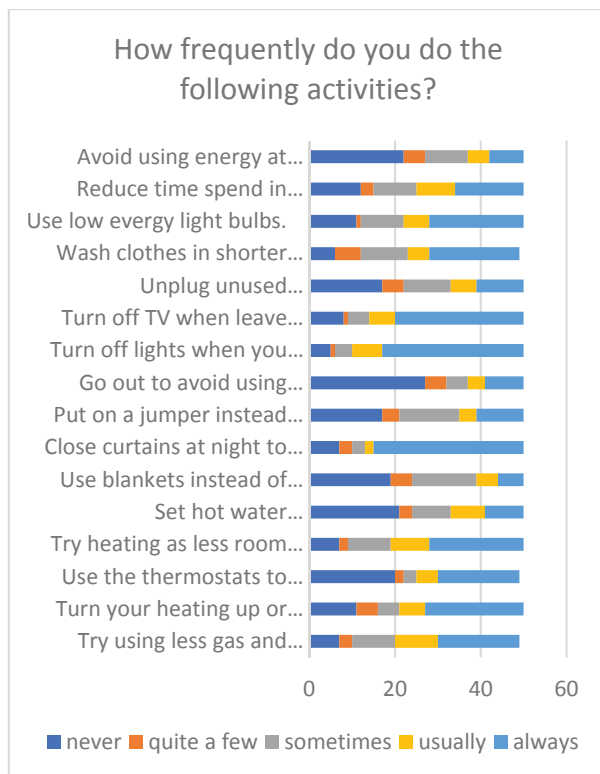


Figure 6. preferred energy related behaviours

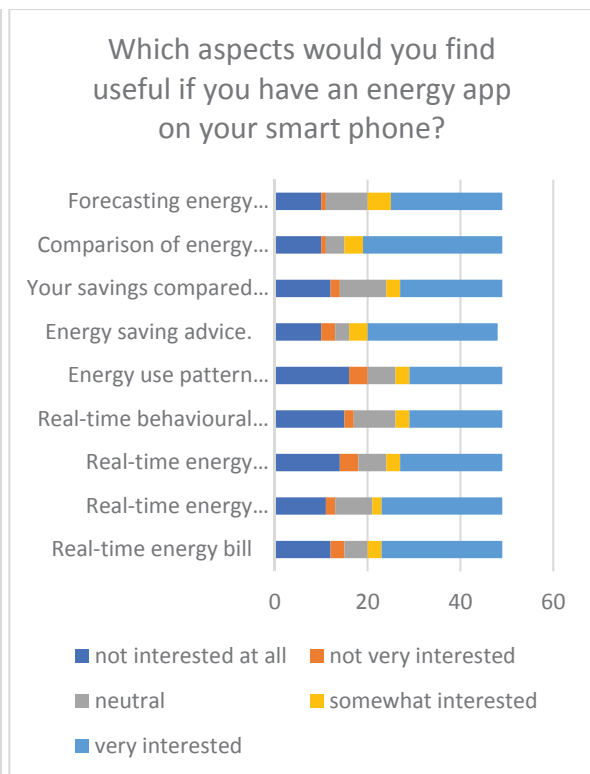


Figure 7. Preferred smart application aspects

According to Figure 6, occupants 'always' save their energy through more conventional ways, such as 'close the curtain' (70 per cent), 'turn off TVs' (60 per cent) and 'turn off the lights' (66 per cent). However, the energy saving behaviours that requires more knowledge and skills were not performed well among the participants: 42 per cent of the occupants will never 'adjust their wall and hot water thermostat', and 44 per cent of them will never 'avoid using energy at peak time'. Besides, people does not want to saving energy by compromising their comfort, that is why 54 per cent of the participants do not like to 'go out avoid using heating' and 36 per cent of them will never 'put on a jumper instead of heating'.

Occupants also rated aspects that they felt would help them reduce their home energy consumption such as 'comparison of energy prices' (61.2 per cent) and 'energy saving advice' (58.3 per cent). However, some approaches have not been fully implemented and facilitated thus they do not draw widely attention, such as 'energy savings compared to your neighbours' (44.9 per cent) and 'real-time behavioural suggestions' (40.8 per cent) In order to draw a picture of those innovative energy saving aspects to the occupants, energy suppliers and the council need to initiate more pilots within their boroughs. Through the case studies, Ehrhardt-Martinez et al (2010) and Hargreaves et al (2013) both indicated that households with comparative feedback displayed in their IHDs tend to use less energy as people may think about the reason why others can achieve low energy consumption than themselves. This can be taken as a social norm feedback which is normally carried out in the communities' level.

#### *Households economic status*

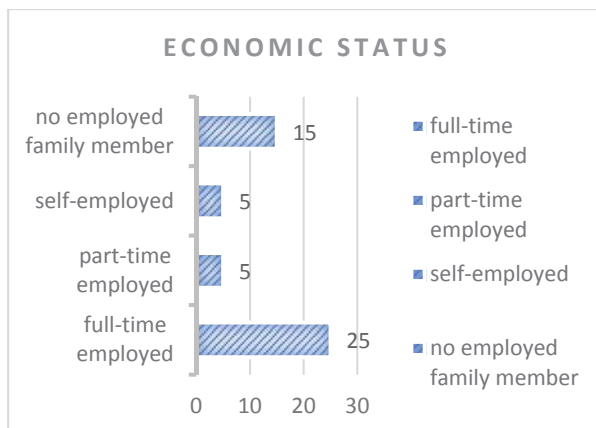


Figure 8. economic status of the family members

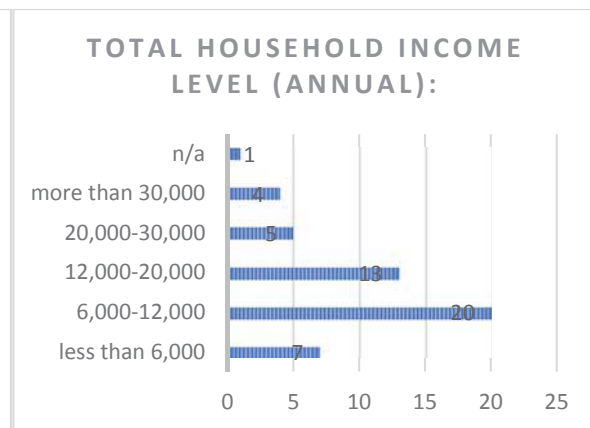


Figure 9. annual household income

Apart from asking occupants' sustainability awareness and their energy related behaviours, their socio-economic factors were also investigated in the questionnaire. According to the Figure 8, households with full-time employed family members take 50 per cent of overall participants; 10 per cent of them have part-time employed family members; 10 per cent of them have self-employed family members, and 30 per cent of them indicated that all of their family members are not able to work. According to the Figure 9, majority (80 per cent) of the households earn less than £20,000 per year. Among these households, 17.5 per cent of them have less than £6,000 annual incomes.

## Discussion

The above-mentioned initial results help to understand the occupants' living conditions, energy use patterns, behaviours, socio-economic backgrounds and their awareness of energy efficiency in social housings. It is noted that there are variety of similarities between the case studies and other social housing tower blocks in London Boroughs such as the construction details, housing conditions and occupants' compositions. With its representativeness of a larger scale of social housings in London, the research aims to reveal the problems that may have not been thoroughly investigated and provide suggestions to councils and the policy makers for more efficient retrofit schemes.

According to the findings, 80 per cent of the households have less than £20,000 total annual incomes. The majority of them are residing in their rented properties for more than 10 years. Although the occupants are experiencing various of housing issues, their energy consumptions are generally not remarkably low or high than each other. Only a few of them will pay attention and try to manage their energy consumption carefully. Most energy usages are in the range between £99 - £300, however, a few of the respondents showed dramatically high heating usages for different reasons such as children's comforts or illnesses. Besides, efforts made from the energy company and government in order to increase occupants' environmental awareness and improve energy efficiency have been found in the survey regarding to the questions of receiving energy advices and changing energy plans/tariffs. However, more efforts are still needed: only less than half of the occupants expressed they have received energy advice and only 34 per cent of the participants have changed their energy plans or energy tariffs mainly for cheaper prices.

More than half the respondents appeared to be able to use their heating systems reasonably according to their own life patterns. Besides, although the majority of the participants have similar heating controls at homes, only less than half of them will frequently use them in the winter. The temperature set on their wall thermostat is also too high. The



majority of the people do focus on opening windows and extractor fans in the winter to get better ventilations. But extractor fans are not equipped at the first estate which needs to be addressed by the local council. Trickle vents are mostly ignored by the occupants as only 34 per cent of the participants will adjust it for ventilation purposes. 86 per cent of the participated households are either leave it open or close forever regardless of the weather. In addition, although great interests have been shown by occupants regarding to energy conservation, the approaches adopted are limited. There are still a lot of efforts can be made on regulating their energy related behaviours. The ones that people were not doing well but proved efficient include set hot water thermostat lower, avoid using energy at peak time, and use blanket instead of heating (Aydin et al, 2017). Participants did not prefer to go out to avoid using heating and put on a jumper instead of heating which mean that occupants do not like saving energy by compromising their living comforts regardless of the household income levels.

Furthermore, the majority of the occupants have sufficient understanding of their energy bills and feel comfortable to read it. The roll-out of smart meters at both estates are not optimistic as it only covers 20 per cent of the sample size in the research. Even for the homes that smart meters are installed, only 50 per cent of the respondents are likely to read it and adjust energy usages accordingly. Only 10 per cent of the respondents expressed that they have energy monitoring applications installed on their smart phones and only one of them will 'sometimes' read it and adjust energy consumption accordingly. Thus, more supports are needed to educate occupants on how to use the energy efficiency applications.

Concerning tackling the BPG, the study focuses on increasing home energy efficiency by taking into consideration of occupants' energy-related behaviours and other socio-economic factors. The study attempts to provide possible solutions for regulating how occupants operate their homes in a more innovative and effective way. In this case, smart metering devices and energy efficiency applications, as part of the smart grid, increase interactions between energy end users and the management level, and thus become the ideal working direction for the future domestic energy conservation. The suggestions are to provide real-time behavioural suggestions to the occupants. The correlations between energy performance and occupant's behaviour need to be thoroughly investigated based on the collected data.

The innovative smart phone application aims to influence at end-users' level by improving energy efficiency by regulating occupants' behaviours through prompts and real-time advice (Shi et al., 2017). As occupants with different demographic and socio-economic status will operate their homes in different ways, the application will require basic input of audience's social and economic backgrounds and quantify these factors based on the found correlations. Then the application is able to identify the proper energy consumption range accordingly and notify the users with alarms/alerts when improper energy uses are detected. Furthermore, it also helps to improve the efficiency of low-carbon retrofit projects by providing the most efficient energy use patterns and behaviours.

## **Conclusion**

The paper firstly identified that the way of meeting UK's CO<sub>2</sub> reduction target in domestic sector is to improve the home energy efficiency and close the BPG of the low-carbon retrofit projects. It provides an innovative perspective to improve the current delivery and performance of low-carbon retrofit through a 'bottom-up' approach by focusing on the occupants' behaviour at energy end-users' level. Based on the review of the literature in this

field, it is believed that rationalising occupants' energy consumption behaviour will help to close the gap between actual energy performance and performance expectations. Besides, energy end-users' socio-economic and other 'hard-to-quantify' factors are also need to be taken into consideration. the paper preliminarily focuses on the survey design of the questionnaire and the initial data analysis. The in-depth data analysis is still ongoing concerning finding other significant correlations between the key variables. In order to increase the interaction between end-users and the energy management systems, the design specification of an innovative smart phone application will be developed as the ultimate research outcome based on the review of existing energy efficiency tools.

In order to fulfil the research aim and objective, a mixed method research design is adopted where a questionnaire survey was designed in order to capture the essential data for the purpose of the research. As a result, 50 questionnaires were returned out of 153 flats. It has been noted that, knowing the occupants' background at case study is essential as it helps to identify appropriate approach and increase responding rate. Sometimes female investigators may be more welcome due to different cultural and religious issues. If the flats with disabled occupants can be identified prior, alternative approaches may apply in order to increase the efficiency of the process. Additionally, as the project is in collaboration with local authority, it would be better if their staffs can be involved in order to increase the reliability of the research and the responding rate of the survey.

According to the completed questionnaires, the initial key findings include: 84 per cent of the households pay less than £300 for their quarterly electricity and gas bills; the economic status was identified relatively low in social housing flats: only 50 per cent of the households have full-time employed family members and 30 per cent of them do not have any employed members; only 34 per cent of the households have previously changed their energy suppliers or energy plans where 60 per cent of them did it for financial reasons; majority (more than 60 per cent) of the participants tend to save their energy by conventional approaches such as 'close curtain', 'turn off TV and lights when leave the room'. However, a number of approaches have not been highly regarded such as 'adjust wall and boiler thermostats' and 'avoid using energy at peak time'. These approaches with certain level of knowledge will need to be popularised with government and professional's supports; at last, according to the open-ended questions, the specific situations may lead to energy over-consumption especially in the social housings, such as illness, lonely elderlies and children's comforts.

## References

- Aydin, E., Kok, N & Brounen, D. (2017). Energy efficiency and household behavior: The rebound effect in the residential sector. *The RAND Journal of Economics*, 48 (3), pp 749-782.
- Barrett, D. (2016). Be Successful & Inspired. [online] Available at: < <http://danabarrett.com/success-owning-your-own-business/>> [Accessed 14 March 2017].
- Carroll, J., Lyons, S & Denny, E. (2014). Reducing household electricity demand through smart metering: The role of improved information about energy saving, *Energy Economics*, 45 (2014), pp234-243.
- Chaudhari, R. B., Dhande, D. P & Chaudhari, A. P. (2014). Home Energy Management System. In the International Conference on Modelling and Simulation in Engineering and Technology ICMSET-2014. Beijing, China. 15-16 Feb 2014. ICMSET: Beijing.
- Climate Change Act 2008. London: HMSO.
- Darby, S. (2010). Smart metering : what potential for householder engagement? *Building Research & Information*, (2010), 38 (5), 442-457.
- Department of Energy and Climate Change (DECC). (2009). The UK low carbon transition plan. London: National strategy for climate and energy, DECC.

- Department of Energy and Climate Change (DECC). (2013). UK Renewable Energy Roadmap, London: DECC.
- Dornyei, Z. (2003). Questionnaires in Second Language Research: Construction, Administration, and Processing. London: Lawrence Erlbaum Associates, Publishers.
- Dowson, M., Poole, A., Harrison, D & Susman, G. (2012). Domestic UK retrofit challenge: Barriers, incentives and current performance leading into the Green Deal, *Energy Policy*, 50 (2012), pp294 – 305.
- Ehrhardt-Martinez, K., Donnelly, K & Laitner, J. (2010). Advanced metering initiatives and residential feedback programs: a meta-review for household electricity-saving opportunities. *Energy Savings and Advanced Metering Meta-Analysis*, ACEEE, United States (2010)
- Environmental Change Institute. (2005). 40% house, Oxford: Environmental Change Institute, University of Oxford.
- Gans, W., Alberini, A & Longo, A. (2013). Smart meter devices and the effect of feedback on residential electricity consumption: Evidence from a natural experiment in Northern Ireland, *Energy Economics*, 36 (2013), pp 729-743.
- Gram-Hanssen, K. (2014) New needs for better understanding of household's energy consumption – behaviour, lifestyle or practices? *Architectural Engineering and Design Management*. 10 (1-2), pp 91-107.
- Greening, L. A., Greene, D. L and Dfiglio, C. (2000). Energy efficiency and consumption — the rebound effect — a survey, *Energy Policy*, 28 (2000), pp 389-401.
- Hadjri, K and Crozier, C. (2009). Post-occupancy evaluation: purpose, benefits and barriers. *Facilities*, Vol 27 Iss: 1/2, 21-33.
- Hague, P. (2006). A practical guide to market research. Surrey: Grosvenor House.
- Hargreaves, T., Nye, M & Burgess, J. (2010). Making energy visible: a qualitative field study of how householders interact with feedback from smart energy monitors. *Energy Policy*, 38 (2010), pp. 6111-6119.
- Hargreaves, T., Wilson, C & Hauxwell-Baldwin, R. (2017). Learning to live in a smart home, *Building Research & Information*, pp 1466-4321.
- Khazzoom, J.D. (1980). Economic Implications of Mandated Efficiency in Standards for Household Appliances, *The Energy Journal*, 1 (4), pp 21-40.
- Ma, Z., Cooper, P., Daly, D. & Ledo, L. (2012). Existing building retrofits: Methodology and state-of-the-art. *Energy and Buildings*, 55, pp 889-902.
- Mathers, N., Fox, N & Hunn., A. (2009). Surveys and Questionnaires. Nottingham & Sheffield: The NIHR RDS for the East Midlands / Yorkshire & the Humber 2009
- Mayes, M. (2017). Homeselfe: The World's Leading Home Energy Saving App. [online] Available at: <https://elemental.green/homeselfe-the-worlds-leading-home-energy-saving-app/> [Accessed 23 Aug 2017].
- Preiser, W.F.E. (1989). Building Evaluation. New York, NY: Plenum.
- Saunders, H. D. (1992). The Khazzoom-Brookes Postulate and Neoclassical Growth, *The Energy Journal*, 4 (1992), 131-148.
- Shi, W., Abdalla, H. & Elsharkawy, H. (2017). An investigation into energy consumption behaviour and lifestyles in UK homes: Developing a smart application as a tool for reducing home energy use. In the International Conference on Passive Low Energy Architecture Design to Thrive (PLEA 2017). Edinburgh, United Kingdom. 2-5 Jul 2017. NCEUB: Edinburgh.
- Sorrell, S and Dimitropoulos, J. (2008). The rebound effect: Microeconomic definitions, limitations and extensions. *Ecological Economics*, 65 (3), 636-649.
- Sunikka-Blank, M and Galvin, R. (2016). Irrational homeowners? How aesthetics and heritage values influence thermal retrofit decisions in the United Kingdom, *Energy Research and Social Science*, 11 (2016), 97-108.
- Technology Strategy Board. (2014). RETROFIT FOR THE FUTURE – Reducing energy use in existing homes. Swindon: Technology Strategy Board.
- United Nations. (1992). United Nations Framework Convention on Climate Change. New York: United Nations.
- United Nations. (1998). Kyoto Protocol to the United Nations Framework Convention on Climate Change. New York: United Nations.
- Webber, P., Gouldson, A and Kerr, N. (2015). The impacts of household retrofit and domestic energy efficiency schemes: A large scale, ex post evaluation, *Energy Policy*, 84 (2015), 35-43.
- Wesley Schultz, P., Estrada, M., Schmitt, J., Sokoloski, R & Silva-Send, N. (2015). Using in-home displays to provide smart meter feedback about household electricity consumption: A randomized control trial comparing kilowatts, cost, and social norms, *Energy*, 90(1), 351-358.

# Investigation of Environmental Conditions in Transitional Spaces of Buildings – Field Studies in Cardiff, UK

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## Abstract

Transitional spaces are popular architectural elements in building designs nowadays; they can be found in the form of atria, lobbies, corridors and covered streets. Being the common features of building developments, they occupy about 10-40% of the total volume of different types of buildings. However, challenges are posed to building designers and engineers in terms of provision of an acceptable thermal comfort for transitional spaces; in fact, thermal discomfort has been revealed in such spaces of several newly constructed buildings. Furthermore, there are still no recommended acceptable comfort range and thermal comfort prediction methods for transitional spaces. This paper aims to investigate the environmental performance and people's adaptive comfort in transitional spaces. During the summer period, field studies, which included on-site questionnaire surveys and physical measurements, were conducted in three selected case buildings in Cardiff. They were The National Assembly for Wales – Senedd, Hadyn Ellis Building and Royal Welsh College of Music and Drama. The total number of 736 responses were collected from the questionnaire surveys. In this paper, the findings from the field studies are first presented, followed by the in-depth investigations on the human adaptability to its thermal environment. Strong correlations between the clothing value and indoor operative temperature were identified. In addition, people's responses to an open question in the questionnaire, which was about how people would act to overcome the uncomfortable situations, were analysed. Two main findings were drawn from this research work. Firstly, fine control of the indoor temperature of transitional spaces is not necessary. Secondly, self-adaptive actions tend to be taken by people to make themselves feel more comfortable in transitional spaces.

**Keywords:** Transitional spaces, thermal comfort, environmental condition, questionnaire survey, adaptability

## 1. Introduction

Transitional spaces have been popular architectural elements in many different kinds of buildings for the past decades. About 10% - 40% of the total volume of different types of buildings are occupied by transitional spaces, which are defined as “unavoidable spaces in non-domestic buildings” (Pitts & Saleh, 2006). Transitional spaces provide both buffer spaces and physical links, as they are located in-between outdoor and indoor environments (Pitts & Saleh, 2007). Transitional spaces take the role of environmental bridges between the interior and exterior environments and provide relaxation spaces for the occupants to enjoy the surroundings. In these spaces, the effects of the external climatic changes are dynamic that the occupants are able to experience (Taleghani, et al., 2014). Transitional spaces can be found in different forms, including seating areas, circulation passages, entrance lobbies, cafeterias and meeting places (Ilham, 2006). From the architectural point of view, the transitional spaces can be attached or unattached to a building development (Monterio & Alucci, 2007).

The climate sensitive and social use of a central courtyard in ancient design can be seen as the origin of the development of transitional spaces (Li, 2007). Transitional spaces have been adopted in building design for about 5000 years (Fathy, 1986; Oliver, 2003). When it comes to the original idea of transitional spaces, this can be traced back to the courtyard design in buildings, which not only served as a central social function space, but

also created a modified climatic environment by providing natural ventilation for the internal spaces (Ahmad & Rasdi, 2000). Similar designs were found later in 10<sup>th</sup> to 11<sup>th</sup> century BC in Siheyuan, a type of Chinese residential houses (Knapp, 2000). Then, later in the 18th century, other central courtyards were found in ancient Roman and Greek houses (Moosavi, et al., 2014), where the term 'atrium' originated from (Hung, 2003). Atriums were designed as the central rooms of the building, and provided connections to all the other chambers (James, et al., 2009). After the Industrial Revolution, atrium buildings became popular (Saxon, 1983). Over the past few decades, as technologies such as new materials including glass and structural materials and computational modelling techniques became more advanced (Samant, 2011), transitional spaces have evolved into different types. Until the present decade, transitional spaces, especially in the form of atrium, have become a dominant feature in built environments (Samant, 2011; Li, 2007).

Although fine control of temperature or comfort limit is not required for transitional spaces, it is still a challenge to the building designer to design such spaces that can provide an acceptable thermally comfortable environment (Pitts & Saleh, 2007). Recent researches reveal that the thermal discomfort is a major issue for transitional spaces. Moreover, lack of research evidence exists in terms of the thermal environment of transitional spaces (Monterio & Alucci, 2007; Hui & Jiang, 2014; Rupp, et al., 2015). Only a few of the studies on comfort environment with dynamic states, including transitional spaces like corridors and atria, have been validated through fieldwork studies, given that the majority of them were conducted in climatic chambers (Palma, 2015). The major focus of these was on the human thermal response to stable environment conditions only (Liu, et al., 2014). This may explain why transitional spaces are still not clearly addressed in the current comfort standards (van Hoof, 2008), where there are still no recommended acceptable indoor temperature ranges for thermal comfort in transitional spaces (Yu, et al., 2015).

By conducting field studies, which included on-site questionnaire surveys and physical measurements in three case buildings in Cardiff, this paper aims to investigate the environmental performance and people's adaptive comfort in transitional spaces.

## **2. Research Methodology**

This research adopted a methodology which included on-site questionnaire surveys and physical measurements in three existing buildings in Cardiff. They were the National Assembly for Wales – Senedd (NAfW), Hadyn Ellis Building (HEB) and Royal Welsh College of Music and Drama (RWCMD), as shown in Figure 1. Before the proposed methodology for the main studies in these three buildings was confirmed, a pilot study had been performed in the Optometry Building of Cardiff University on 21<sup>st</sup> July 2017. A thoroughly review of the study was conducted, which included the feedbacks obtained during the pilot study. The proposed methodology was then optimised before carrying out the main studies. A mixed method, involving a combination of quantitative and qualitative approaches, was adopted to achieve the research aims. During the field studies, the measurements on indoor and outdoor environmental conditions were carried out at the same time the questionnaire surveys were taking place.





Figure 1. Surveyed buildings and their indoor environments

## 2.1 Surveyed Buildings

The selected buildings were located in different locations in Cardiff, where the distance from the outdoor weather station ranged from 0.1 km to 2.8 km. These buildings were selected based on the following major selection criteria:

1. The building shall be within 3 km from the weather station, in order to ensure the representation of the recorded weather data;
2. The selected buildings shall cover different functional types; and
3. The buildings shall have large and publicly accessible transitional spaces where the response rate and thus representativeness of the questionnaire survey could be ensured.

Table 1 summarises the key characteristics of the surveyed buildings. The building types of these buildings were different, but they were all publicly accessible during their opening hours. Building Management System (BMS) was incorporated to automatically control the windows in order to enhance the ventilation during warm days and to maintain more desirable thermal comfort level within the buildings. Three days in the summer period were spent in each of the selected buildings for the field studies, which included questionnaire surveys and physical measurements.

Table 1. Key characteristics of surveyed buildings

Surveyed building	NAFW	HEB	RWCMD
Building established	2006	2012	2011 (refurbished)
Building type	Public / Government	Academic	Academic / Cultural
Building area	5,120 m <sup>2</sup>	9,740 m <sup>2</sup>	4,400 m <sup>2</sup>
No. of stories	3	5	3
Major façade type	Glazed	Glazed	Glazed
Windows open strategy	Automatic	Automatic	Automatic
Distance from weather station	2.8km	0.6km	0.1km
Survey dates	19 August 2017 20 August 2017 26 August 2017	4 August 2017 8 September 2017 12 September 2017	20 September 2017 21 September 2017 22 September 2017
Survey period	10:30 – 16:30	08:30 – 17:30	08:30 – 19:00



## 2.2 Physical Measurements

While the questionnaire surveys were being conducted, the indoor environmental parameters were also monitored. These included air temperature, relative humidity, air velocity and black globe temperature. It was ensured that the accuracy of the instrumentations used for the field studies could meet the requirements of ASHRAE 55-2013 (ASHRAE, 2013). The details of the instrumentations that were used in the field studies are summarised in Table 2. The coverage areas of the measurement included the indoor transitional spaces involving the entrance lobby, atrium and café area. In order to ensure the representativeness of the readings throughout the surveyed areas, the best measurement location was identified by carrying out measurements in different locations within a space. The intervals for air speed measurement was set at 15 minutes and all the other parameters were monitored at every single minute. The measurement instruments were set up in at least 30 minutes before the start of the field studies to ensure that steady state of the environmental measurements had been reached. The physical measurement covered the whole period of the questionnaire surveys. The measurement locations were set at 1.1 m height from floor. Outdoor environmental parameters were recorded by a weather station (model: Campbell Instruments CR10 data logger), which was installed on the rooftop of Bute Building, the Architectural School of Cardiff University, at 5-minute intervals. Rotronic temperature and humidity probe in radiation shield was installed to measure the air temperature and relative humidity.

Table 2. Measurement range and accuracy for the instruments used for the field studies

Parameter	Instrumentation model	Range	Accuracy	Accuracy requirements ASHRAE 55
Air temperature	Tinytag Ultra 2 Temperature and Relative Humidity Logger	-25°C - 85°C	±0.5°C (for range 0-40°C)	Minimum: ±0.5°C Ideal: ±0.2°C
Relative humidity	Tinytag Ultra 2 Temperature and Relative Humidity Logger	0% - 95%	±3% (at 25°C)	±5%
Black-globe temperature	Tinytag Talk 2 Temperature Logger (with 40mm black table-tennis ball)	-40°C - 125°C	±0.4°C (for range 0-70°C)	Minimum: ±2°C Ideal: ±0.2°C
Air speed	Lutron AM-4204 Anemometer	0m/s - 20m/s	±0.05m/s (for up to 1m/s)	±0.05m/s

## 2.3 Questionnaire Surveys

In order to collect subjective data from the building occupants for comfort evaluation in the specified locations of the surveyed buildings, a standardised questionnaire was developed. The questionnaire included 24 questions, which adopted a combination of open-ended, partially closed-ended and predominantly closed-ended questioning approaches. The questionnaire was designed to collect both quantitative and qualitative feedbacks from the respondents. As presented in Table 3, 7-point scale and 5-point scale methods were adopted for the thermal sensation questions and thermal and sunlight preference questions respectively. Besides, an open question “how would you overcome uncomfortable situations, if any” was designed in the questionnaire, in order to investigate people’s adaptability to thermal environment. Additional data, including demographic data, activity

level, clothing insulation, time spent and feedbacks in the interviewed location, locations and time spent of previous space, and previous thermal experience in the interviewed location, were also collected from the questionnaire. During the questionnaire survey, building users were randomly selected within the transitional spaces of the surveyed buildings. Necessary guidance and elaboration of the survey questions were given for some of the respondents.

Table 3. Sensation and preference scale used in the survey

Scale	Overall Thermal Feeling	Thermal Comfort Sensation	Humidity Sensation	Air Movement Sensation	Thermal Preference	Sunlight Preference
+3	Very pleasant	Hot	Very humid	Very draughty	-	-
+2	Moderately pleasant	Warm	Moderately humid	Moderately draughty	Much warmer	Much more
+1	Slightly pleasant	Slightly warm	Slightly humid	Slightly draughty	A bit warmer	A bit more
0	Neutral	Neutral	Neutral	Neutral	No change	No change
-1	Slightly unpleasant	Slightly cool	Slightly dry	Slightly still	A bit cooler	A bit lesser
-2	Moderately unpleasant	Cool	Moderately dry	Moderately still	Much cooler	Much lesser
-3	Very unpleasant	Cold	Very dry	Very Still	-	-

## 2.4. Data Analysis

Statistical Package for Social Sciences (SPSS) version 23 was adopted for the analysis of the data collected from the field studies, which had been compiled into spreadsheets. Separate analysis was carried out according to surveyed buildings and specified locations within the buildings. Pearson correlation coefficients were computed to assess the correlation between pairs of variables. Correlations between multiple parameters collected from the questionnaire surveys and physical measurements were carried out in order to investigate the relationship between different parameters. The significance level of the analysis was set to be 0.05. In other words, the results were statistically significant when  $p\text{-value} < 0.05$ .

## 3. Results and Analysis

### 3.1 Descriptive Analysis

A total number of 736 responses were collected from the questionnaire surveys throughout the summer period, where 282, 207 and 247 surveys were contributed by NAFW, HEB and RWCMD respectively. This is comparable to other reviewed literatures on the subject of thermal comfort, which adopted questionnaire survey as part of the methodology. The total number of surveys acquired in these comparable studies ranged from 114 to 967 (Yang & Zhang, 2008; Kántor, et al., 2012; Hou & Tweed, 2014; Xue & Xiao, 2016; Majewski, et al., 2017).

Due to the difference of the building functions and settings in the indoor transitional spaces of these buildings, the monitored and surveyed results were different. Details can be found in Table 4.

Table 4. Summary of the surveyed and monitored results

		NAfW	HEB	RWCMD
Total responses (N)		282	207	247
Male respondents		110 (39%)	81 (39%)	115 (47%)
Female respondents		172 (61%)	126 (61%)	132 (53%)
Age	Mean	42	32	26
	SD	18	10	10
Clothing value (clo)	Mean	0.50	0.60	0.60
	SD	0.17	0.20	0.20
Activity level (met)	Mean	1.44	1.30	1.18
	SD	0.48	0.47	0.46
Outdoor temperature (°C)	Mean	18.14	16.62	16.41
	SD	2.30	1.84	1.33
Outdoor Relative humidity (%)	Mean	64.88	67.25	67.69
	SD	10.88	10.53	9.76
Outdoor Air Speed (m/s)	Mean	2.54	2.51	2.98
	SD	1.68	0.76	0.79
Indoor temperature (°C)	Mean	20.85	22.71	22.93
	SD	1.32	1.02	0.92
Indoor Relative humidity (%)	Mean	43.60	45.30	57.26
	SD	5.26	9.32	6.79

\* Temperatures shown were the record taken during the time when the questionnaire survey was conducted

NAfW is a government building that is open to the public. Since the special event “Poppies – weeping window” was held during the surveyed period, the majority of respondents from the survey were visitors to the building. Guided tours were regularly being offered by the building management team, which were usually started in the atrium space on the Ground Floor at designated times. Lesser responses could be collected from the atrium space because the main purpose of most of the visitors who stayed in the atrium was just for the tours. On the contrary, a significant amount of responses was collected from the exhibition area and café area on the First Floor. As a larger portion of people watched the exhibition, or appreciated the building architectural design and the functional use of the different parts of the building by standing or walking, the average activity level of the respondents was higher than for the other two surveyed buildings. The measured indoor temperature was found to be the lowest, even though the outdoor temperature monitored during the questionnaire survey was highest among all the surveyed buildings. This could be explained by the natural ventilation of the building as windows were opened to ventilate the building during the surveyed period of time.

HEB is an institutional research building, where facilities such as offices, laboratories, meeting spaces, and seminar and lecture rooms are provided for university students or researchers to carry out various types of academic activities. The average age of the respondents was lower than that of NAfW, as most of the respondents were undergraduate and postgraduate students. Since more chairs and sofas were set up for the building users, a more significant number of respondents used the transitional spaces for resting and dining. The portion of respondents whose main activity in the transitional spaces was sitting was larger when compared to NAfW. Therefore, HEB had a lower average activity level than NAfW. The windows were closed most of the time during the survey period. On some

occasions, when the temperature rose up, the windows were opened to allow natural ventilation.

RWCMD is an academic building which also provides a cultural experience for building users. In comparison with HEB, a more significant number of respondents was undergraduate and postgraduate students, since the academic term started when the questionnaire survey was conducted. Therefore, the average age of respondents from RWCMD was the lowest among all the surveyed buildings. The average activity level of the respondents was lowest when compared to the other two surveyed buildings as a great number of chairs and tables were provided for the building users in the atrium space and café area. The respondents were mainly sitting. The windows were closed all the time during the survey period. This may explain why the average monitored indoor temperature was higher than the other buildings.

Figure 2 illustrates the frequency distribution chart of the thermal sensation votes (TSV). It shows the results collected from questionnaire surveys in the three surveyed buildings – NAFW, HEB and RWCMD. Among the three surveyed buildings, the TSV distribution was similar, where the majority of respondents voted “neutral” for the thermal comfort and the rest of them tended to have a warmer feeling. As defined by ISO 7730:2005 (ISO, 2005), 80% acceptability comfort band falls between TSV of -1 and +1. For NAFW, HEB and RWCMD respectively, about 85%, 83% and 76% of the respondents were found in the 80% acceptability comfort band. In addition, about 94%, 82% and 91% of the respondents felt pleasant (i.e.  $TSV \geq +1$ ) for the overall thermal feeling for NAFW, HEB and RWCMD respectively. In order words, the thermal environment of all the three surveyed buildings made people feel comfortable in the transitional spaces. The average vote for the overall thermal feeling for NAFW (mean: 2.25; SD: 0.96) is the highest among the surveyed buildings, while that for HEB (mean: 1.58; SD: 1.27) was lower than that for RWCMD (mean: 1.89; SD: 1.08).

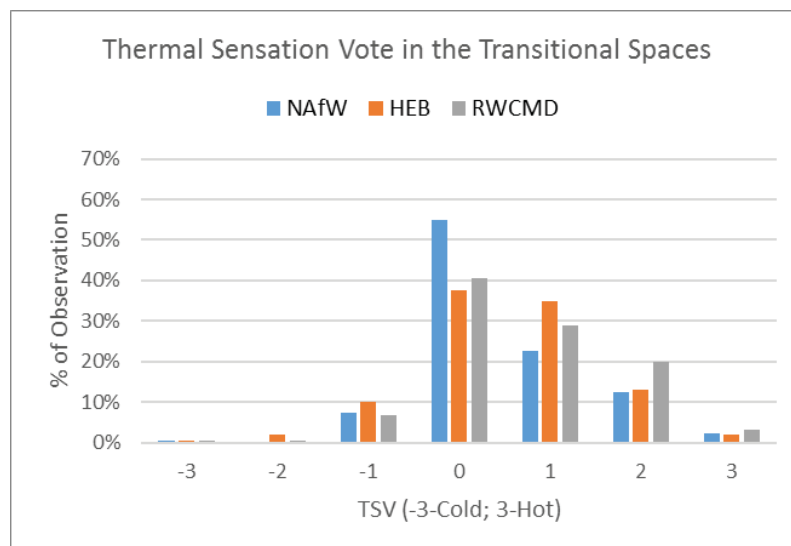


Figure 2. Frequency distribution of thermal sensation votes (TSV)

### 3.2 Correlation Analysis

In order to evaluate the correlation between different parameters, Pearson (2-tailed) correlation analysis was conducted. Only few parameters had strong correlations that could be applied to all the three surveyed buildings. As to fulfil the research objective, only clothing value against indoor operative temperature and outdoor temperature were filtered out for further investigations. Table 5 summarises the correlation results, from which a

better correlation was found between clothing value and indoor operative temperature when compared to that with outdoor temperature. The relationship was stronger for NAFW than for the other two surveyed buildings. In addition, NAFW was found to have the best correlation between clothing value and indoor operative temperature ( $p < 0.01$ ). However, such correlations for the HEB and RWCMD were weaker, but they were still statistically significant ( $p < 0.05$ ).

Table 5. Correlation results for clothing values of all surveyed buildings

	Clothing Value		
	NAFW	HEB	RWCMD
Indoor Operative Temperature	-0.384**	-0.260*	-0.145*
Outdoor Temperature	-0.386**	-0.072	-0.107

\*significant at  $p < 0.05$

\*\*significant at  $p < 0.01$

### 3.3 Investigation of Influence of Indoor Operative Temperature on Clothing Value

With reference to ASHRAE Standard 55-2013 (ASHRAE, 2013) and ISO 7703:2005 (ISO, 2005), the reported respondents' clothing in the questionnaire surveys were converted into numerical figures. A binned method was adopted to eliminate the outliers by setting the increments of indoor operative temperature at half-degree-Celsius. Figure 3 shows the graphical results of the averaged clothing values against the indoor operative temperature for each surveyed building. A strong linear relationship between these two parameters was identified, as the coefficient of determination ( $r^2$ ) ranged from around 0.71 to 0.91. The gradient between these parameters was negative. In other words, the higher the indoor operative temperature, the lower the clothing value was.

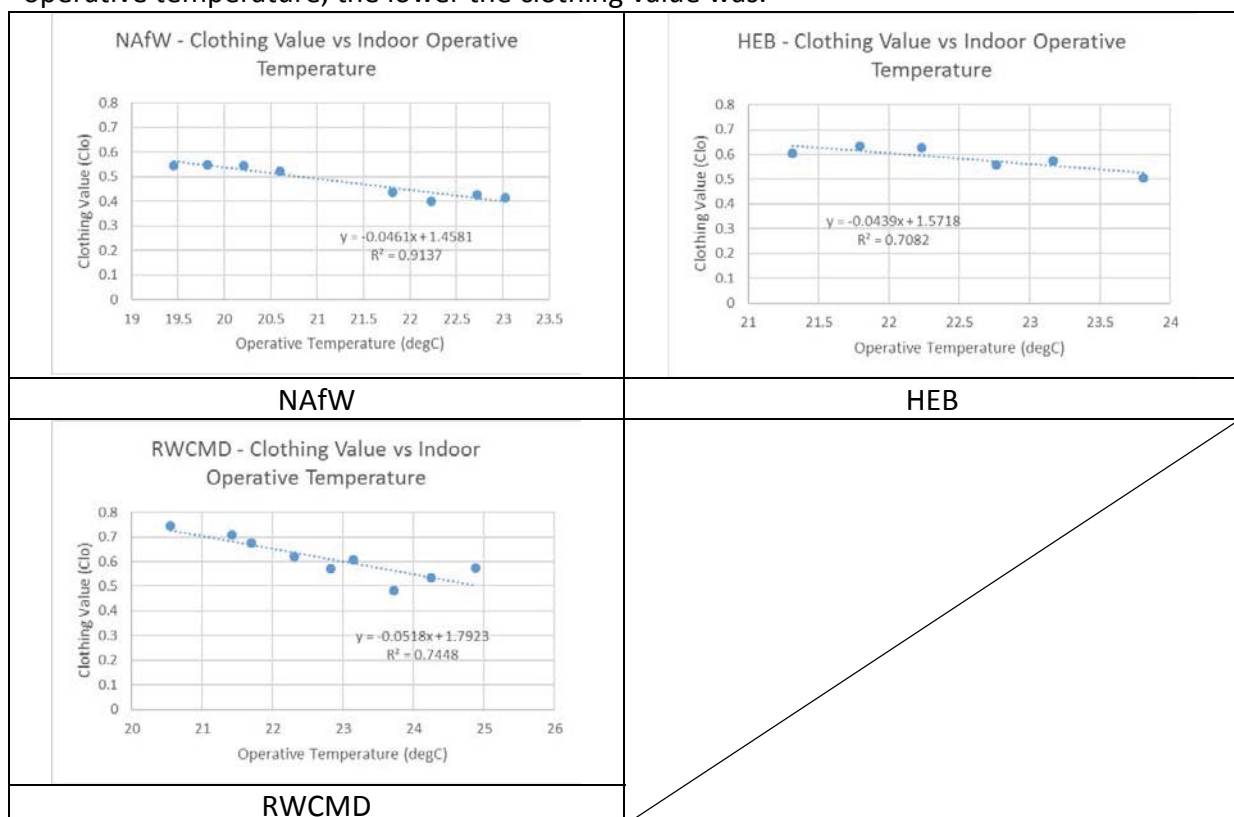


Figure 3. Influence of indoor operative temperature on clothing value

### 3.4 Investigation of Influence of Outdoor Temperature on Clothing Value

Similar studies were carried out for the relationship between clothing value and outdoor temperature. Figure 4 illustrates the results. It was identified that the relationship between clothing value and outdoor temperature was similar to the one between clothing value and indoor operative temperature, i.e. the gradient was also negative. The difference was that the correlation between clothing value and outdoor temperature was weaker. The coefficient of determination ( $r^2$ ) ranged from 0.23 to 0.41.

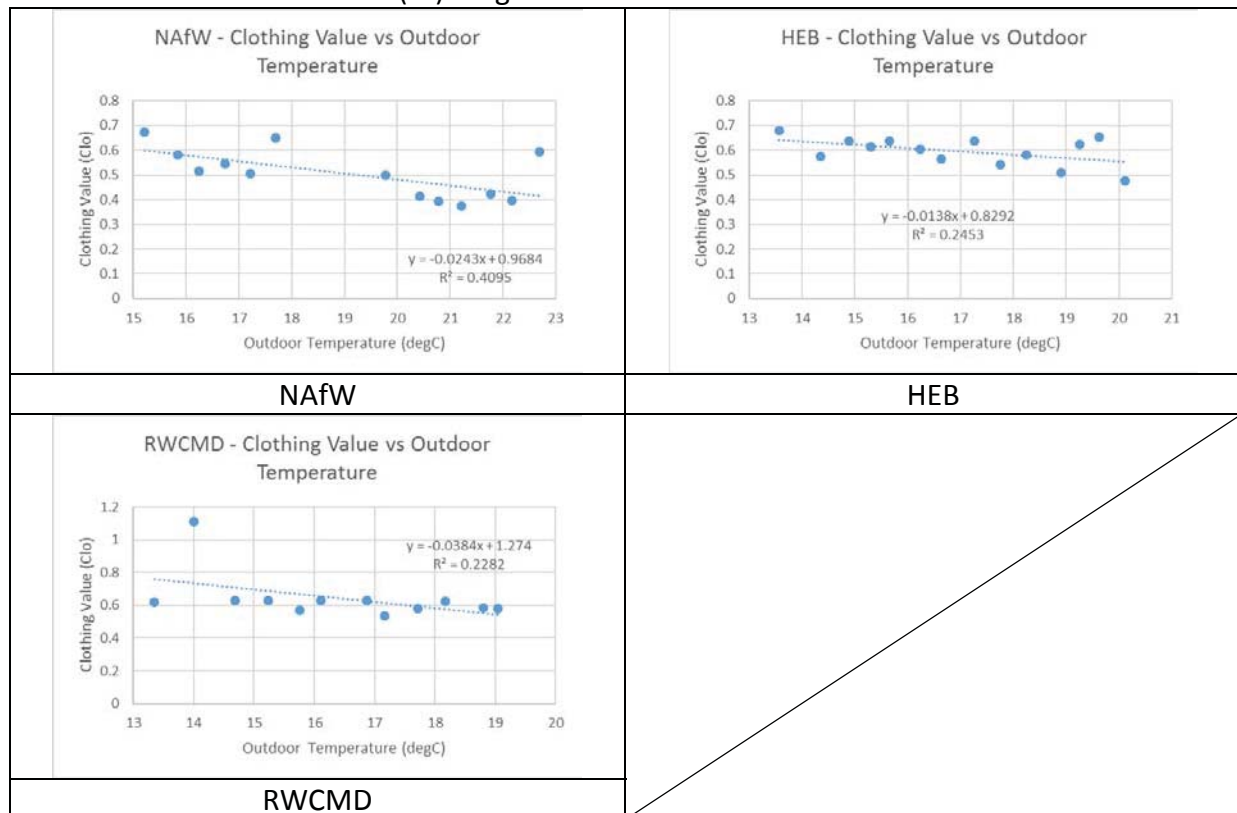


Figure 4. Influence of outdoor temperature on clothing value

### 3.5 Investigation of Actions that People Would Take to Overcome Uncomfortable Situations

In order to investigate how the respondents would act to overcome uncomfortable situations, an open question was designed in the questionnaire. The response rate for this question was 320, or 43.5%, out of the total 736 surveyed questionnaires for the three surveyed buildings. More than one answer was given by some respondents. Therefore, in total, 339 answers were collected from the respondents. Since this was an open question, as expected, replies were worded differently. However, they could be classified into 8 groups, namely “adjust clothing”, “use mechanical means”, “drink/eat”, “move/leave from the uncomfortable location”, “report to building staff”, “do exercise”, “close the openings” and “other”. For instance, answers such as “take off jackets”, “add a layer of clothing” and “put scarf / cardigan on” were categorised as “adjust clothing”. Rare answers such as “talk my way through” and “more light” were grouped as “other”. The details about the respondents’ actions to overcome uncomfortable situations were summarised in Table 6.

Categories such as “adjust clothing”, “drink / eat”, “move / leave from uncomfortable location” and “do exercise” were treated as self-adaptive actions, which meant that the respondents would act differently without changing the environmental conditions to make



themselves feel more thermally comfortable. It was found from the results that in order to overcome uncomfortable situation, a vast majority (nearly 80%) of the respondents opted for self-adaptive actions. In other words, people tend to adapt themselves to the thermal environment instead of trying to alter the building operations.

Table 6. Summary of respondents' actions to overcome uncomfortable situations

<b>Categorised actions to overcome uncomfortable situations</b>	<b>NAfW</b>	<b>HEB</b>	<b>RWCMD</b>	<b>Total</b>
Adjust clothing	55 (54%)	43 (44%)	71 (50%)	<b>169 (50%)</b>
Move / Leave from the uncomfortable location	23 (23%)	14 (14%)	35 (25%)	<b>72 (21%)</b>
Use mechanical means	11 (11%)	12 (12%)	11 (8%)	<b>34 (10%)</b>
Close the openings	1 (1%)	16 (16%)	6(4%)	<b>23 (7%)</b>
Drink / Eat	4 (4%)	4 (4%)	10 (7%)	<b>18 (5%)</b>
Other	2 (2%)	4 (4%)	6 (4%)	<b>12 (4%)</b>
Report to building staff	2 (2%)	3 (3%)	1 (0%)	<b>6 (2%)</b>
Do exercise	3 (3%)	2 (2%)	0 (0%)	<b>5 (2%)</b>
<b>Total response rate</b>	<b>101 (30%)</b>	<b>98 (29%)</b>	<b>140 (41%)</b>	<b>339</b>

#### 4. Discussions

It was found from the data analysis that the thermal comfort level was highly acceptable by the building users, considering that a significant number of respondents (>82%) voted the overall thermal feeling as "pleasant" (> +1 vote) in all the three surveyed buildings. Moreover, more than 80% of the respondents fell within the 80% acceptability comfort band, where TSV between -1 and +1 was voted. The range of comfort level of these buildings was not too significant, even though the variation of the indoor temperature was greater than 4.5°C.

Due to the strong correlations that were identified during the correlation analysis, the influences of the indoor operative temperature and outdoor air temperature on clothing value were also investigated. These correlations showed similar trends, just that stronger correlation between the clothing value and indoor operative temperature was identified. This can be explained by the fact that appropriate clothing was probably chosen according to the outdoor air temperature before the people left from indoor environments. Subsequently, in order to adapt to the thermal environment and make themselves feel more thermally comfortable, they would adjust their clothing after entering the space where they felt thermally uncomfortable.

The investigation of the actions that the people would opt to take to overcome uncomfortable situations reinforced the statement. Almost 80% of the respondents would take self-adaptive actions to keep themselves warmer or cooler when they felt cool or warm. These included "adjust clothing" (50%), "Move / Leave from the uncomfortable location" (21%), "Drink / Eat" (5%), and "Do exercise" (2%). Therefore, from this research study, it can be concluded that people would act to adapt to the thermal environment and make themselves feel thermally comfortable. Therefore, a fine control of indoor temperature is not necessary for transitional spaces.

## 5. Conclusions

Investigations on the environmental performance of building transitional spaces were carried out by this research work. Field studies, which included questionnaire surveys and physical measurements, were conducted in three different selected buildings in Cardiff during the summer period in 2017. They were The National Assembly for Wales – Senedd, Hadyn Ellis Building and Royal Welsh College of Music and Drama. A total number of 736 responses collected from the building occupants were analysed.

A pleasant overall thermal feeling with the environment in transitional spaces was expressed by the vast majority of the respondents from all the three surveyed buildings. Although there were some differences in a number of factors such as age, activity level, indoor temperature and clothing values, the thermal sensation vote was similar, where 76% - 85% of the respondents voted within 80% acceptability comfort band ( $\pm 1$  TSV) for these surveyed buildings. The human thermal adaptability was further investigated by correlating the reported clothing value against indoor operative temperature and outdoor temperature respectively. Linear relationships with negative gradients were found from both comparisons, where the correlation for the impacts of indoor operative temperature on clothing value was much stronger.

In addition, investigations on the actions that people would take to overcome uncomfortable situations were also carried out. The answers from the respondents were grouped into eight categories, which were “adjust clothing”, “drink/eat”, “move/leave from the uncomfortable location”, “do exercise”, “use mechanical means”, “report to building staff”, “close the openings” and “other”. The first four categories were treated as self-adaptive actions, where people would act to adapt themselves to the thermal environment without trying to change the environmental conditions. It was found that nearly 80% of the respondents would take self-adaptive actions to overcome uncomfortable situation. This enhanced the findings of the strong correlation between clothing value and indoor operative temperature. The higher the indoor operative temperature, the less clothing value was reported in the questionnaire surveys. In other words, people would tend to reduce their clothing, such as taking a layer off, when the indoor operative temperature rose, or vice versa. In trying to understand the human thermal adaptability to its environment, it was concluded from the research that fine control of indoor temperature is not necessary for acceptable thermal comfort in transitional spaces. On the basis of this research, further research works on quantifying the comfort temperature range and methods to provide all-year-round comfortable environment in transitional spaces are recommended.

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## 6. References

Ahmad, M. H. & Rasdi, M. T. H. M., 2000. *Design Principles of Atrium Buildings for the Tropics*. Malaysia: Penerbit UTM.

- ASHRAE, 2013. *ANSI/ASHRAE Standard 55 - Thermal Environmental Conditions for Human Occupancy*. Atlanta: American Society of Heating, Refrigerating and Air- Conditioning Engineers.
- Fathy, H., 1986. *Natural energy and vernacular architecture: principles and examples with reference to hot arid climates*. Chicago: The University of Chicago Press.
- Hou, G. & Tweed, C., 2014. *A field study of thermal comfort in transitional spaces in buildings in Cardiff, UK*. Windsor, UK, Proceedings of 8th Windsor Conference.
- Hui, S. C. M. & Jiang, J., 2014. *Assessment of thermal comfort in transitional spaces*. Hong Kong, Kowloon Shangri-la Hotel, Tsim Sha Tsui East, Kowloon.
- Hung, W. Y., 2003. Architectural Aspects of Atrium. *International Journal on Engineering Performance-Based Fire Cordes*, 5(4), pp. 131-137.
- Ilham, S., 2006. *Thermal comfort in transitional spaces in desert communities: the study of cases in Tucson, Arizona*. Tucson: The University of Arizona.
- ISO, 2005. *ISO 7730, Ergonomics of the Thermal Environment—Analytical Determination and Interpretation of Thermal Comfort Using Calculation of the PMV and PPD Indices and Local Thermal Comfort Criteria*. Geneva: International Standard Organization.
- James, P., Jentsch, M. & Bahaj, A., 2009. Quantifying the added value of BiPV as a shading solution in atria. *Solar Energy*, Volume 83, pp. 220-231.
- Kántor, N., Égerházi, L. & Unger, J., 2012. Subjective estimation of thermal environment in recreational urban spaces - Part 1: investigations in Szeged, Hungary. *International Journal of Biometeorology*, 56(6), pp. 1075-1088.
- Knapp, R. G., 2000. *China's Old Dwellings*. Honolulu: University of Hawaii Press.
- Li, R., 2007. *PhD Thesis: Natural ventilation of atrium spaces*, Sheffield, UK: School of Architecture, The University of Sheffield.
- Liu, H. et al., 2014. The response of human thermal perception and skin temperature to step-change transient thermal environments. *Building and Environment*, March, Volume 73, pp. 232-238.
- Majewski, G., Telejko, M. & Orman, Ł. J., 2017. Analysis of Thermal Comfort in an Intelligent Building. *Civil and Environmental Engineering*, 13(1), pp. 72-76.
- Monterio, L. M. & Alucci, M. P., 2007. *Transitional spaces in São Paulo, Brazil: Mathematical modeling and empirical calibration for thermal comfort assessment*. Beijing, Building Performance Simulation Association Conference and Exhibition.
- Moosavi, L., Mahyuddin, N., Ghafar, N. A. & Ismail, M. A., 2014. Thermal performance of atria: An overview of natural ventilation effective designs. *Renewable and Sustainable Energy Reviews*, Volume 34, pp. 654-670.
- Oliver, P., 2003. *Dwellings: the house across the world*. Oxford: Phaidon Press Ltd..
- Palma, G. A. V., 2015. *Short-term thermal history in transitional lobby spaces*, Sheffield: The University of Sheffield.
- Pitts, A. & Saleh, J. B., 2006. *Transition Spaces and Thermal Comfort – Opportunities for Optimising Energy Use*. Geneva, PLEA2006 - The 23rd Conference on Passive and Low Energy Architecture.
- Pitts, A. & Saleh, J. B., 2007. Potential for energy saving in building transition spaces. *Energy and Buildings*, pp. 815-822.
- Rupp, R. F., Vasquez, N. G. & Lamberts, R., 2015. A review of human thermal comfort in the built environment. *Energy and Buildings*, Volume 105, pp. 178-205.
- Samant, S., 2011. *PhD Thesis: A parametric investigation of the influence of atrium facades on the daylight performance of atrium buildings*, Nottingham, UK: University of Nottingham.
- Saxon, R., 1983. *Atrium Building: Development and Design*. 2nd Edition ed. London: Architectural Press.
- Taleghani, M., Tenpierik, M. & Dobbelsesteen, A., 2014. Energy performance and thermal comfort of courtyard/atrium dwellings in the Netherlands in the light of climate change. *Renewable Energy*, Volume 63, pp. 486-497.
- van Hoof, J., 2008. Forty years of Fanger's model of thermal comfort: comfort for all?. *Indoor Air*, Volume 18, pp. 182-201.
- Xue, S. & Xiao, Y., 2016. Study on the Outdoor Thermal Comfort Threshold of Lingnan Garden in Summer. *Procedia Engineering*, Volume 169, pp. 422-430.
- Yang, W. & Zhang, G., 2008. Thermal comfort in naturally ventilated and air-conditioned buildings in humid subtropical climate zone in China. *International Journal of Biometeorology*, Volume 52, pp. 385-398.
- Yu, Z., Yang, B. & Zhu, N., 2015. Effect of thermal transient on human thermal comfort in temporarily occupied space in winter - A case study in Tianjin. *Building and Environment*, Volume 93, pp. 27-33.

# Suitability of neighborhood-scale massing models for daylight performance evaluation.

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**Abstract:** Access to daylight in buildings is the combined effect of a building's own physical attributes along with its surrounding physical context. There is thus growing interest among researchers to extend the use of building performance simulation (BPS) tools for daylight performance evaluation, not just for an individual building, but to the neighborhood scale and beyond. In the design process of neighborhoods, massing models are often utilized and are a pivotal early design-stage work-product. These models are typically simple and delineate broad geometric dimensions of built enclosures. They are thus attractive for fast early design stage assessment using BPS tools and maybe used to determine daylight access potential. However, at this stage, the designer may have limited and imprecise information regarding the building façade, the vital element for daylight intake and distribution in the building interior.

In this study, we assess the dependability of simple massing models for comparative indoor daylight assessments of neighborhood forms. Useful Daylight Illuminance (UDI) metric based performance values were calculated for five neighborhood design options using common practice for façade related inputs in early design stage simulation models and then ranked in decreasing order of performance. A virtual progression of the design-process was then carried out to develop multiple plausible façade design solutions for all proposed massing schemes. The main finding of this study is that significant changes can be observed in neighbourhood rankings when increasing the degree of detail in the façade design solutions. While the highest performing designs were found to maintain their ranks, the rankings of other projects shifted considerably when façade related information was supplied. This work informs on the possibility of erroneous design decisions resulting from simplified façade inputs in early design stage models and fosters the growing discussion on appropriate utilization of BPS tools for informing design decisions.

**Key Words:** BPS best practice, design process, daylight, façade details

## Introduction

The world is currently witnessing the largest urban population growth in history. According to projections by the United Nations ("UN DESA 2014"), by the year 2050, the world's urban population will increase by 2.5 billion. While increasing urbanization brings about resource efficiency and economic growth, it also affects the ability of the new and existing built environment to rely on natural resources such as daylight to create comfortable spaces for habitation. The role of architects and architecture today is thus of critical importance. In his revolutionary book in the year 1923 (Corbusier, 1923), architect Le Corbusier, described a house as 'a machine to live in' and that 'architecture is the masterly, correct and magnificent play of masses brought together in light'. Growing pressures of urbanization and the urgent need to address our building use related carbon-emissions are now demanding greater precision in the building design process; and that architects be 'masterly' and 'correct' in order to deliver pleasurable, healthy, comfortable, energy-efficient urban living environments.

Daylight, a critical element of the indoor environmental quality, is modulated by each scale of the physical environment (Cammarano et al, 2015), from the urban scale right down to a single room. While the pre-existing urban context may partially determine the nature and amount of daylight access, it is up to the building design team to harvest the available resources for a given a project. In the context of the architectural design process, massing models, whether created in

sketch, 3D modeling material or computing medium play a crucial role. Early in the design process, quick and simple models are often developed to examine, evaluate and discuss design ideas (Akin and Moustapha, 2004; Kvan and Thilkaratne, 2003). Kvan et al, highlight that models in the architectural design process, especially early on, tend to be diagrammatic or representative in nature and they develop along the design process. A number of design decisions may be taken based on the exchange that happens amongst the design team while examining these models. A number of daylight researchers have thus been trying to target this design activity while the project is taking shape.

In this study, we are interested in this design activity at the neighborhood level, i.e. the intermediate scale between an individual building and the urban scale. The neighborhood scale is indeed unique as the design team has control over both the overall form of the neighborhood and also building scale decisions. In the following section, we thus discuss tools that are specifically targeted at a neighborhood scale early-design phase. These tools allow architects and designers to understand the relationship between architectural characteristics of neighborhood forms and daylight access.

### **Methods for evaluating daylight in early neighborhood designs**

Early design tools for daylight can be divided into two primary categories 1) rules of thumb and 2) simulation based. Similar to the early rule-of-thumb based urban-scale solar design-aids developed by Knowles (Knowles, 1974, 2003), DeKay (DeKay, 2010) proposed the 'Daylight Envelope' concept as an urban scale daylight design tool. The Daylight Envelope technique produces a three-dimensional enclosure creating a permissible boundary that achieves the design goal for Daylight Factor. The model is based on empirical observations of urban block dimensions, street widths and resulting Daylight Factors achieved. However, the Daylight Factor metric itself has serious limitations. It ignores several critical factors when designing a daylit space such as the orientation of the building, climatic effects such as cloud cover and time-varying nature of sky and sun positions.

Compagnon (Compagnon, 2004) presented an indoor work-plane illuminance evaluation method for neighbourhood designs based on simulation of vertical illuminance on the exterior building facades. This computationally light method can be used to compare various neighbourhood forms. It regards window openings as daylighting devices and they are grouped under 'utilization factors' when estimating the combined effect of buildings at a neighborhood scale. In order to successfully integrate time-consuming annual daylight simulations in the transient early design phase, the speed of simulation has been one of the key concerns of researchers. For example, a fast daylight performance calculation algorithm was developed by Dogan et. al. (Dogan et al, 2012). Similar to (Compagnon, 2004), the incident illuminance on the vertical facades is first calculated. These values are then translated into indoor illuminance values using a 2-D light propagation algorithm. This method was used in the development of an interactive design tool called Urban Modeling Interface (UMI) (Reinhart et al, 2013) for rapid evaluation of massing models. Their intent was to assist architects in making connections between good daylight performance and building/urban morphology. A very different approach was used by Nault et al (Nault, 2016) in developing a tool called UrbanSOLve that also allows architects to quickly evaluate their design performance to other parametrically generated design variants. The



tool is based on a meta-model generated by collecting performance data (Spatial Daylight Autonomy) from a large set of representative neighborhood massing schemes.

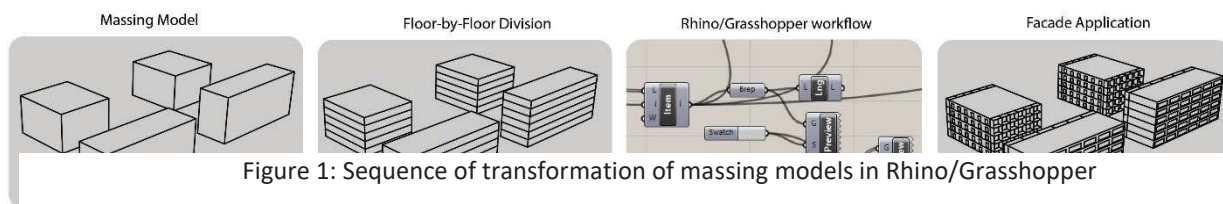
While these tools are able to evaluate and compare the performance of neighborhood layouts with acceptable margins of error when compared to full-scale simulations, they take a simplistic view of the façade. Several researchers working at the urban and neighbourhood scale (Sattrup and Strømman-Andersen, 2013; Dogan et al, 2012; Compagnon, 2014) support simple façade related inputs for urban scale studies based on the idea that the influence of the volumetric and relative building layout on site tends to outweigh that of the façade composition.

However, this assumption is more likely to hold true if we assume that the windows are distributed uniformly across the façade, in which case form related factors would dominate. Both urban (Ratti et al, 2005) and room level studies (Gibson, 2014; Ratti et al, 2005; Wright and Mourshed, 2009) find that placement of windows with respect to the internal configuration of the building can have appreciable affect both quantity of daylight intake (Ratti et al, 2005) and its distribution. New climate based metrics such as Spatial Daylight Autonomy (IESNA, 2012) and Useful Daylight Illuminance (Nabil Mardaljevic et al, 2006; Mardaljevic, 2015) simultaneously evaluate the amount of daylight received indoors and also how well it is distributed (temporally and spatially) in order to support the activities of the occupants. Under these conditions, it seems imperative that we investigate the reliability of massing models that do not carry any specific information regarding the façade design.

## Methodology

In this study we evaluate if ignoring façade related design information and only evaluating the massing of the neighborhood could lead to erroneous decisions when selecting the high performance designs. We tested this by carrying out annual daylight simulations for five possible neighborhood massing schemes for hypothetical project located in Geneva, Switzerland. Using the parametric modelling environment, Rhino/Grasshopper (McNeel, 2015, 2013), we add façade related information to the massing models in a step-by-step manner. Facade parameters that are included are described in the façade details section below.

Using various combinations of these façade details, we virtually propagate the design process for each of the massing schemes. Each massing scheme is taken through three explicit steps of increasing resolution in both the façade design and its representation in the simulation models. In order to represent the many possible decision-making paths that could be followed to arrive at a certain degree of definition in façade design, three scenarios are created, described in the design scenario section below. With each evolutionary step of the design process, we evaluate if the top performing massing schemes are able to retain their ranking. The façade design approach is kept strictly consistent using the same grasshopper workflow each time so as not give



unwarranted advantage to any particular neighborhood design. The façade generating grasshopper work flow is given a massing scheme which has been split into floors and one or more



façade design parameters as inputs. The workflow generates a 3-D geometry file with façade elements such as windows and shading elements added to the massing scheme (Figure 1). Since the workflow remains unchanged with each massing scheme, it allows us to study if a particular façade design approach has greater synergy with a particular form more so than others.

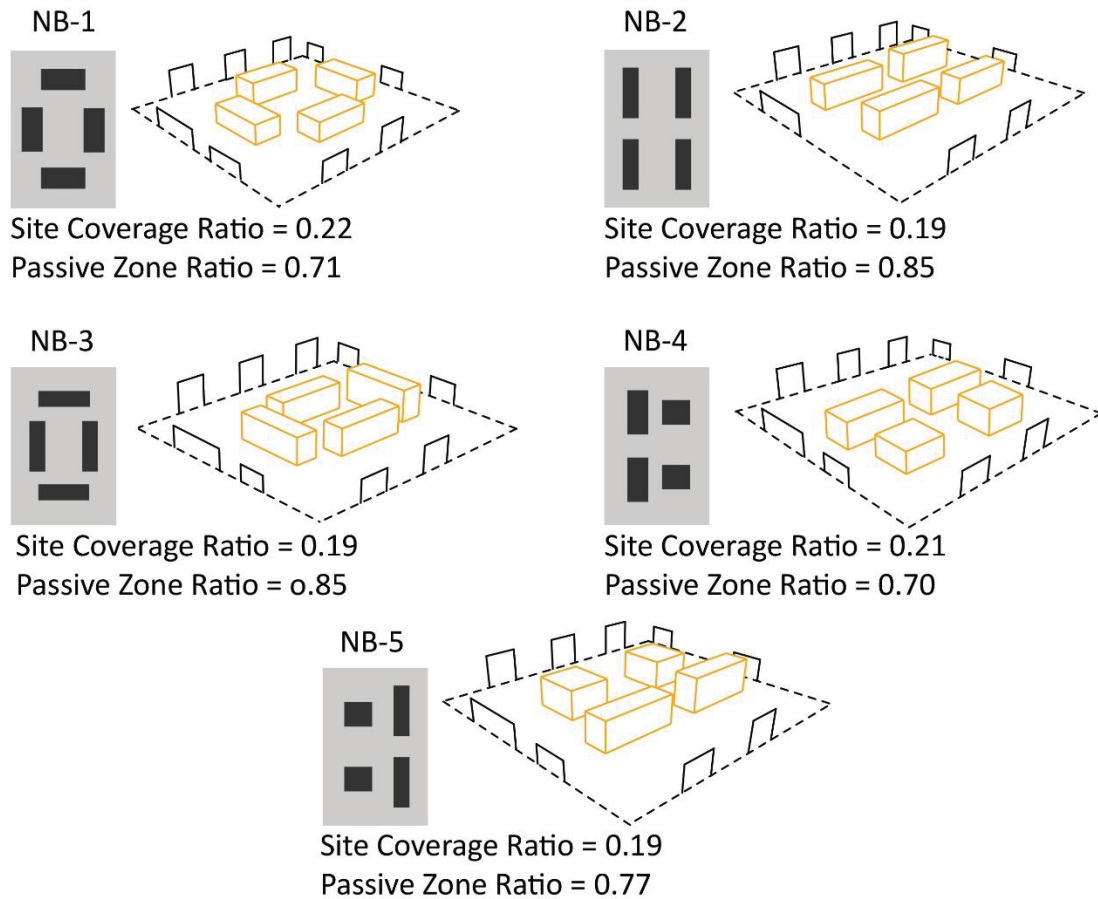


Figure 2: Proposed neighbourhood massing schemes included in the study

The proposed massing schemes are inspired largely by observations of existing neighborhoods in the Genève area. Density (built area/site area or floor-area-ratio) of 1.0 was chosen and then the number of floors, building aspect ratio and arrangement on site was drawn from observations of a set of existing neighborhoods. Given the rich variety in façade types found in residential buildings, we found it more pertinent to conduct this test on residential buildings. The schemes produced are shown in figure 2. Site coverage ratio presented is calculated as building foot-print/site area. Passive zone ratio is the ratio of floor area within 6m of the façade to the total floor area (Baker and Steemers, 1996).

For this study, the performance evaluation criteria used is Useful Daylight Illuminance (Mardaljevic, 2015). The UDI metric is largely developed from user assessments of office spaces. It regards the range of 100-3000 lux in horizontal illuminance as useful while acknowledging that the lower illuminance range of 100-300 lux is useful but insufficient for common office related tasks such as reading. The metric thus has provision to regard the 100-300 lux illuminance range achieved by daylight as supplementary and not fully autonomous. Since in this study the subject

buildings are residential and majority of residential spaces by area (living areas and bedrooms) host several activities that are not detail oriented (social meetings, dining and household chores), the range 100-300 lux is likely to be useful in the residential setting as well. We recognize that 100-300 lux illuminance might not be sufficient for all activities in residential buildings, however we are not evaluating auxiliary artificial lighting energy use in this study and thus continue using UDI with its original intent. On the other end applying an upper limit for preferred horizontal illuminance (rather than luminance-based glare-related discomfort) is a subject of ongoing research (Kleindienst and Andersen, 2012; Wienold, 2009). It is being included here as a very appreciable proxy for visual comfort for initial investigations at this scale. Regarding shading, which greatly influences visual comfort and overheating prevention, the effect of fixed shading devices (e.g. balconies) – when appropriate to consider in a massing model (cf. façade design parameter “C” described below) – will be accounted for, but operable blinds will not be considered at this time given the scale of the daylight simulations.

Climate based annual daylight simulations were carried out in Radiance/Daysim (Ward-Larson and Shakespeare 1998; Reinhart and Walkenhorst 2001) with the evaluation period modified to 7:00 AM to 7:00 PM in the evening to reflect relevant daylit hours at home rather than at work. In the daylight simulation model, a square grid of sensors, 1 m apart was set up across all zones/spaces in the neighborhood massing schemes. These sensor points act as virtual photo-sensors. The illuminance data at each point for every hour is assessed against the pass/fail criteria of UDI (100lux-3000lux). Every hour that the illuminance falls in this range is counted as meeting the UDI criteria. Refer to Table 1 for key material parameters. Other simulation parameters such as ambient bounces and ambient divisions were kept consistent with IESNA guideline for the modelling method for climate based daylight simulation metric sDA (IESNA, 2012).

Table 1: Surface properties assigned for daylight simulations

Surface type	Property	Value
Glazing	Visible light transmittance	0.6
Internal Walls	Reflectance	0.5
Internal Floor	Reflectance	0.3
Internal ceiling	Reflectance	0.8
External Wall	Reflectance	0.3
External fixed shading devices	Reflectance	0.3

#### *Façade details considered*

In this study three kinds of façade design parameters are being considered based on the combined considerations of common modelling practices, common design features of residential building facades and the potential impact of these elements on daylight distribution.

Facade design parameter A) Window area to wall area ratio (WWR)

Facade design parameter B) Identification of a prominent façade and a secondary façade per building and including a bias in window opening area

Facade design parameter C) Presence and location of fixed shading devices.

Façade design parameter-A: In this study simple specification of WWR is being referred to as façade design parameter A (Figure 3). The only information that is passed on to the simulation

model under this parameter is the percent value of glazed area at the building level. The common practice for preparing a massing model for annual daylight simulation is followed when applying façade design parameter A, and windows with arbitrary aspect ratio are input as two-dimensional openings along all faces of the buildings. Another common default input, that is also followed, placing windows at the centre of the wall surface vertically and spacing them equally, horizontally.

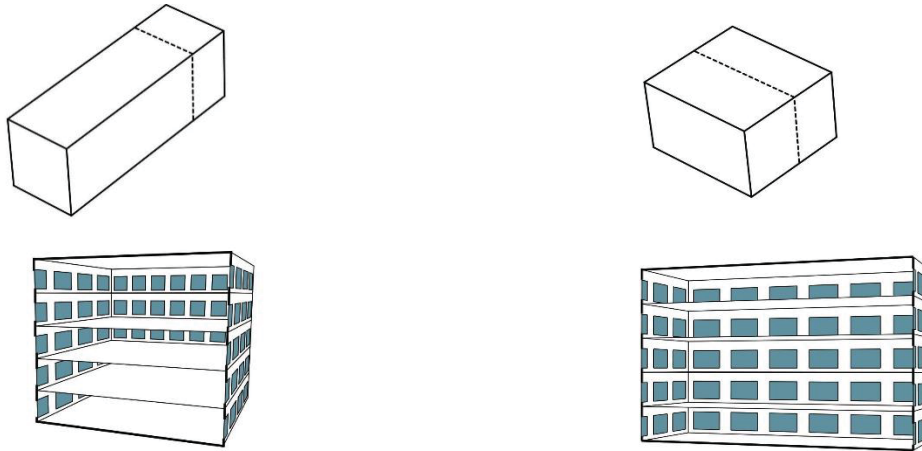


Figure 3: Example of addition of facade design parameter A using Rhino/Grasshopper to example building blocks (example on left shows sectional view of a long linear building, example on right shows a sectional view through a building with aspect ratio<1.25)

Façade design parameter-B: Under this parameter we recognize that not all building faces will carry the same WWR and that certain facades of the same building may have different WWR. Under this façade design parameter, we take the following design steps: 1) identify the prominent and secondary façade surfaces 2) define the ratio of the glazing area assigned to the prominent and the secondary façade. The selection of prominent and secondary façade is based on the orientation of facades and overall form of the building (Figure 4).



Figure 4: Examples of application of façade design parameter B (example on left shows sectional view of a long linear building, example on right shows a sectional view through a building with aspect ratio<1.25)

Façade design parameter-C: Fixed shading devices have an important role in daylight intake and distribution in the interior and improving visual comfort for the building occupant. These would also be typically excluded from early design performance evaluations. However, horizontal projections like balconies are a common design feature in residential buildings. We regard them as facade design parameter C (Figure 5). In order to test the hypothesis, an intensive version of balcony types is utilized in this study. The balconies assigned are 2.4 m deep, cover the entire prominent facade and also have vertical elements on both sides for privacy, forming an egg crate shading device.



Figure 5: Examples of application of façade design parameter C (example on left shows sectional view of a long linear building, example on right shows a sectional view through a building with aspect ratio<1.25)

### *Design scenarios considered*

We present three different scenarios in which varying degrees of information regarding the façade are input during the initial daylight assessment at the onset of the project. In scenario 1, no specific façade details are known. Default values are assumed and they are eventually corrected in subsequent design steps. In scenario 2 WWR value is known fairly accurately and other façade design details are added eventually (table 2). In scenario 3, The design team is able to specify the prominent facades but does not know the WWR to be used on the project. In each case, they would like to assess the performance of the five neighborhood massing schemes.

Table 2: Design scenarios considered

	Initial assessment inputs	Virtual design step I	Virtual design step II
Scenario 1	Only facade design parameter A is set, 40% WWR is assumed	<ul style="list-style-type: none"> <li>WWR corrected to 30%</li> <li>Facade design parameter B is added</li> </ul>	<ul style="list-style-type: none"> <li>Facade design parameter C is added</li> </ul>
Scenario 2	Only facade design parameter A is is set, 40% WWR is assumed	<ul style="list-style-type: none"> <li>WWR unchanged</li> <li>facade design parameter B is added</li> </ul>	<ul style="list-style-type: none"> <li>facade design parameter C is added</li> </ul>
Scenario 3	Facade design parameter B is specified, façade design parameter A is set to 40%	<ul style="list-style-type: none"> <li>facade design parameter A is changed to 30%</li> </ul>	<ul style="list-style-type: none"> <li>Facade design parameter C is added</li> </ul>

### **Results**

We first examine the simulation results at the space level, how the addition of various façade details changes the daylight distribution in the building interior. Two example spaces with the deepest cross-sections (20m and 26m) were chosen for further examination. We then go on to

examine the results at the neighborhood scale under the three design scenarios described above.

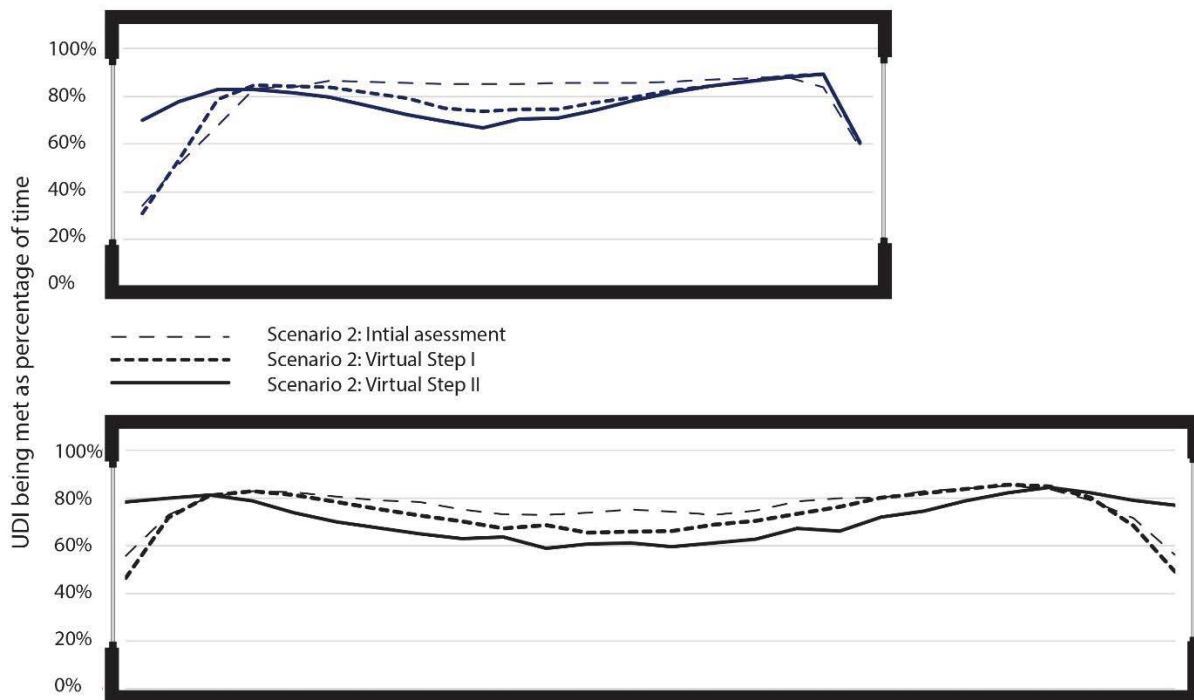


Figure 6: Percent of time UDI is met, shown in cross section of the example spaces (space proportions in section are indicative, not to scale)

### Space Level Results

Figure 6. shows the variation in UDI achievement as a percentage of time over the year, across two example spaces for scenario 2. In this scenario, the WWR remains constant and the results thus show changes in performance achieved only with changes in window placement and addition of balconies. The space shown on the top in Figure 6 is 20 m deep and has East/West windows on either side. The space shown on the bottom in Figure 6 is 26 m deep and has windows on all faces with the prominent facades facing East/West.

In both examples spaces, we find that the areas near the window opening are the poor performing areas during the initial assessment phase. Understandably this changes only when the balconies are added (façade design parameter C). The addition of balconies/fixed shading brings more hours during the year under the upper limit of 3000 lux and results in the improvement of UDI achievement. The middle section of the space, farthest from the windows appears to be affected by both distribution of glazing across the facades (façade design parameter B) and the addition of balconies (façade design parameter C).

If we examine the annual average percentage of time UDI is met across the two cross-sections presented in Figure 6, we find a difference of -4.5% and -3.8% between the initial assessment and virtual design Stage I in the 26 m deep space and the 20 m deep space respectively. These differences occur by only changing the window area distribution from one façade to another. If we compare the annual average percentage of time UDI is met between the

initial assessment and virtual design step II we find greater fluctuation in the 26m deep space (-6.8%), than the 20m deep space (-2.4%).

### Neighbourhood Level Results

Scenario 1: Under scenario 1, we observe several changes in performance ranking of the neighborhoods examined with incremental addition of façade details. While the top two performing neighborhoods maintained their ranks throughout the virtual progression of the design process, middle rank holding neighborhoods were found to be volatile in their rankings (Figure 7). The biggest changes in rankings were seen at the virtual design Step I when the window wall ratio was corrected and the prominent facades were identified. Virtual design Step II helped distinguish between the top performing designs suggesting that NB-3 was more sensate to placement and addition of balconies and was adversely effected in UDI evaluation. Ranking and relative performance of other neighborhoods remained largely unchanged at the virtual design Step II.

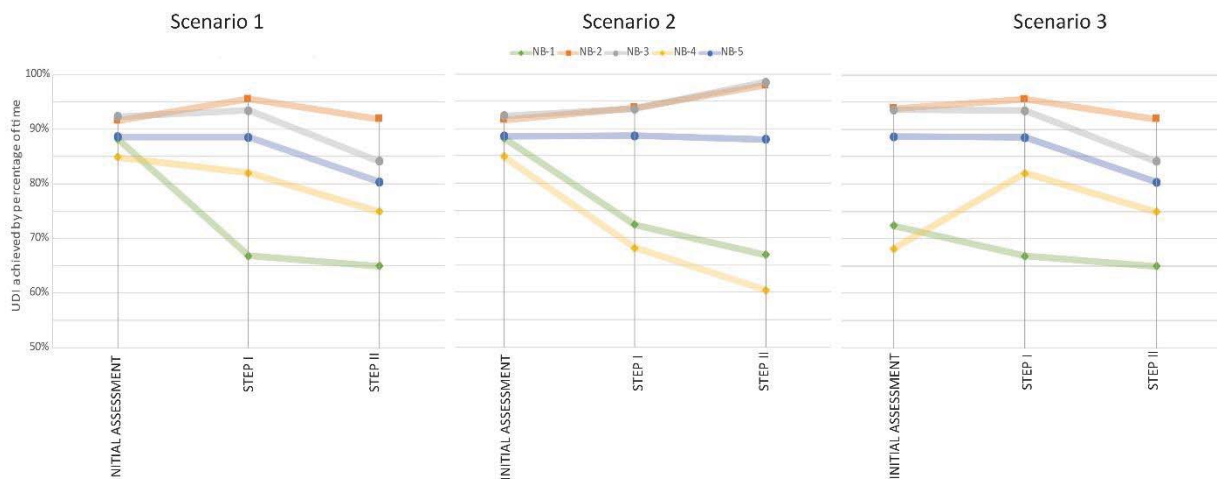


Figure 7: UDI performance values under scenario 1,2 and 3

Scenario 2: In scenario 2 also we observe one change in performance rankings of the neighborhoods examined. The initial estimate of the design team regarding the WWR here happens to be correct and remains unchanged throughout the progression shown. While the rankings, in this case, are found to be more consistent than scenario 1, we see some neighborhoods (NB-2,3,5) continue to improve in performance as more façade details are added. Performance of other neighborhoods (NB-1,4) continuously drops. In other words, a decision which would seem somewhat irrelevant in terms of daylight performance in the absence of façade design details (e.g. choosing between NB1 and NB2) can become of significant influence should one consider certain façade parameters (only revealed in steps I and II).

Unlike scenario 1, one can note that the performance of the top two performing neighbourhoods (NB -2,3) remains within 1% of each other even at virtual design step II. This could be explained due to the fact that in this case the WWR ratio remained high and thus neither neighbourhood is affected unfavourably with the addition of shading devices. In scenario 1, the



performance of NB-3 (neighbourhood with courtyard layout) drops with addition of virtual design step 3 at 30% WWR.

Scenario 3: In scenario 3 we start the assessment from a point where the design team is able to include façade design parameter B (location of prominent facades) from the very onset of their evaluations. In this case, the neighborhoods with low performance at the initial assessment are found to be volatile in their rankings. Addition of balconies (façade parameter C) helps in differentiating between the top two performing neighborhoods (NB-1,2). It is also noteworthy that in this scenario, the performance of NB-4 improves with the reduction in glazed area, contrary to other neighbourhood schemes, where the performance either drops or remain nearly constant. While the overall WWR applied to all the neighbourhoods at a certain design step is kept consistent, the amount of glazing per façade, especially after inclusion of design parameter B depends on the total available surface area per building and proportion of area of the prominent façade. For example, in Scenario 3, at the initial assessment stage, while the overall WWR is 40%, the prominent façades of the long linear building in NB-1 carry 45% WWR but in NB-4 the long linear buildings carry 60% WWR on the prominent facades. NB-4 then appears to benefit from a reduction in the overall WWR in the virtual design step I. Existing parametric studies (Berardi and Anaraki, 2015; Cammarano et al, 2015) involving design factors such as WWR, room depth when evaluating UDI show that increasing WWR results in lower UDI levels near the window while increasing the UDI levels in the back of the room. However, to further understand the inter-relationship between other factors included this study, such as building placement, orientation, passive zone ratio and daylight performance, a parametric approach is needed which we hope to address in future studies.

### *Summary*

Rank changes were found to be most severe when information input at the initial assessment was limited to WWR and if the default value chosen was not adhered to later on in the design process. However, the two high-performance cases were able to retain their rank in all cases. The top-performing cases were neighborhoods composed of buildings with the highest passive zone ratio. No clear trends were observed with regards to the site coverage ratio. It became possible to distinguish between the top performers only upon addition of balconies in the low window-wall-ratio case (30% WWR). At 40% WWR their performances remained within 1-2% of each other. Thus it appears that change in rank and relative performance is not only subject to differences in form but also the façade parameters.

Active shading devices such as internal or external blinds/drapes are a common feature of window openings in residential buildings and play an important role in maintaining visual and thermal comfort indoors as per the occupant's needs. While occupant behaviour plays a large role in how they are used and operated, their use is also affected by design choices such as presence or absence of fixed shading devices or self-shading. The use of blinds for alleviating conditions of glare has been ignored in the study. It has been considered in a very simplistic manner in this study using the contentious upper limit of horizontal illuminance included in the UDI metric. We hope to address this in future in future studies.

## Conclusions

In this study, we wanted to test if massing models could be reliably ranked in order of performance during the early design stage. By incrementally adding façade related information we tested if a minimal amount of specificity in the façade inputs could improve the reliability of massing models.

Initial assessments done using only WWR input, resulted in a relatively small spread in performance values across the proposed massing schemes. The overall range in performance at the initial assessment stage (Scenario 1 and 2) was found to be 7.4% (in annual average UDI). Adding information regarding the prominent facades in scenario 2 substantially expanded the range of performance to 25.6%. This large spread in performance allows for more confident early design stage performance evaluations when a large number of other design parameters are still unknown.

Current findings suggest that adding one or more façade details can greatly improve the reliability of massing models for daylight performance evaluations. However, they are hard to generalize as only limited façade design possibilities were tested. In future studies, we would like to explore multiple design possibilities resulting in a probability of rank changes rather than single observations.

Façade details were found to not only aid in clearly distinguishing the performance of the various massing schemes, but in some cases the design decisions could be different depending on the knowledge of the architect regarding the façade. The performance rankings were found to differ based on the chosen value of WWR per building, WWR per facade and location of fixed shading. The effect of these factors on rankings was also found to vary between the neighbourhood schemes evaluated. Thus the design decision related utility of the façade design factors in the early design performance evaluations was found to be contingent upon the subject neighbourhood(s) being evaluated. We propose a parametric approach to further understand the relationship between neighbourhood form characteristics, the resulting massing schemes and the need for façade related information for robust performance evaluation.

While findings in this paper are drawn from an example project and are empirical in nature, they inform the growing debate on robust early design phase performance evaluations using simulation tools. We find that daylight performance evaluations may not only be subject to modelling practices and evaluation criteria, but also the design process followed and degree of integration of performance evaluations into the design process.

## References

- Akin, O., Moustapha, H., 2004. Strategic use of representation in architectural massing. *Design Studies* 25, 31–50. [https://doi.org/10.1016/S0142-694X\(03\)00034-6](https://doi.org/10.1016/S0142-694X(03)00034-6)
- Baker, N., Steemers, K., 1996. LT method 3.0 - A strategic energy-design tool for southern Europe. *Energy and Buildings* 23, pp. 251–256.
- Berardi, U., Anaraki, H.K., 2015. Analysis of the Impacts of Light Shelves on the Useful Daylight Illuminance in Office Buildings in Toronto. *Energy Procedia*, 6th International Building Physics Conference, IBPC 2015 78, 1793–1798.
- Camarano, S., Pellegrino, A., Verso, V.R.M.L., Aghemo, C., 2015. Assessment of daylight in rooms with different architectural features. *Building Research & Information* 43, pp. 222–237.
- Compagnon, R., 2004. Solar and daylight availability in the urban fabric. *Energy and Buildings* 36, pp. 321–328.
- Corbusier, L., 1923. *Toward an Architecture*. Getty Publications.
- DeKay, M., 2010. Daylighting and Urban Form: An Urban Fabric of Light, pp. 35–56.
- Dogan, T., Reinhart, C., Michalatos, P., 2012. Urban daylight simulation calculating the daylit area of urban designs. *IBPSA-USA Journal*. 5(1). pp. 613-620

- Gibson, M.D., 2011. Integrating geometry and light: daylight solutions through performance-based algorithms. *Considering Research: Reflecting Upon Current Themes in Architectural Research*, pp.111.
- IESNA, 2012. IES LM- 83-12, Approved Method: IES Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE), IESNA Lighting Measurement. New York, NY, USA.
- Kleindienst, S., Andersen, M., 2012. Comprehensive annual daylight design through a goal-based approach. *Building Research & Information* 40, 154–173.
- Knowles, R.L., 2003. The solar envelope: its meaning for energy and buildings. *Energy and buildings* 35, pp. 15–25.
- Knowles, R.L., 1974. *Energy and form: an ecological approach to urban growth*. The MIT Press, Cambridge, MA, USA.
- Kvan, T. and Thilakaratne, R., 2003, September. Models in the design conversation: architectural vs. engineering. In *Aasa-American Association of School Administrators Conference Proceedings* (pp. 222-233)
- Mardaljevic, J., 2015. Climate based daylight modelling and its discontents. In: *CIBSE-Technical-Symposium-2015*, CIBSE Chartered Institute of Building Services Eng.
- McNeel, 2015. Grasshopper. Robert McNeel & Associates, Seattle, USA.
- McNeel, 2013. Rhinoceros v. 5.0. Robert McNeel & Associates, Seattle, WA, USA.
- Nabil Mardaljevic, J., Nabil, A., Mardaljevic, J., 2006. Useful daylight illuminances: A replacement for daylight factors. *Energy and Buildings* 38, 905–913.
- Nault, E., 2016. *Solar Potential in Early Neighborhood Design. A Decision-Support Workflow Based on Predictive Models* (PhD Thesis). Ecole polytechnique fédérale de Lausanne, Lausanne, Switzerland.
- Ratti, C., Baker, N., Steemers, K., 2005. Energy consumption and urban texture. *Energy and Buildings* 37, pp. 762–776.
- Reinhart, C.F., 2004. Lightswitch-2002: a model for manual and automated control of electric lighting and blinds. *Solar Energy* 77, pp. 15–28.
- Reinhart, C.F., Dogan, T., Jakubiec, J.A., Rakha, T., Sang, A., 2013. UMI - An urban simulation environment for building energy use, daylighting and walkability, in: *Proceedings of BS2013*. Presented at the 13th International Conference of International Building Performance Simulation Association (IBPSA), IBPSA, Chambéry, France.
- UN DESA 2014, n.d. URL <http://www.un.org/en/development/desa/news/population/world-urbanization-prospects-2014.html> (accessed 9.29.17).
- Wienold, J., 2009. *Daylight glare in offices*. Fraunhofer-Verlag.
- Wright, J.A., Mourshed, M., 2009. Geometric optimization of fenestration. In: *Proceedings of the Eleventh International IBPSA Conference, (Building Simulation 2009)*, 27-30 July, Glasgow, Scotland, pp. 920-927.

# Holistic sensitivity analysis on urban geometry and its effect on building performance in hot arid zones

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## Abstract

There is a need to assess the growth of urban communities through analytical frameworks that have a multi-objective and holistic approach. In this paper, a sensitivity analysis was conducted on urban geometry with a holistic and integrative approach as it has a significant influence on the building heat loss/gain that determines the energy demand needed to achieve indoor thermal comfort. Simulation tools that analyse urban geometrical variables are available in commonly used parametric design software. This study analysed urban geometrical variables such as (height, built area ratios, orientation and window to wall ratio). In addition, it gives an insight into the buildings' inter-shadowing effect by adding the context buildings' built area ratio in the tested grid. Furthermore, the study includes daylighting sensitivity analysis by changing the lighting control systems. Two sets of materials were used to refine the results for the study conducted for the city of Aswan in Egypt which has a hot arid climate. Additionally, the study investigated the effect of changing lighting controls (standard ON/OFF controls vs. dimmers) on cooling energy consumption. Using the Daylight autonomy results to change the lighting schedules of the tested energy zones is time-consuming, suggesting that the daylighting distribution is better suited for later design stages rather than being a key component of energy analysis in early design stages. The geometrical variables' relative importance on energy performance on the energy demand for cooling of mid-rise residential buildings in hot arid zone urban configuration are as follows: Window-to-wall ratio (WWR); built area ratios; heights; and finally orientation. The results of this study show the need for a staged approach to early stage design with increasing simulation complexity as the design develops. This can be achieved in a single environment where simulation components are carefully combined.

**Keywords:** Parametric simulation, energy demand, lighting control, daylighting, urban geometry

## Introduction

The world urbanization is expected to continue its growth for at least the next 10 years. As it is stated by UNFPA 2007 report. *"In developing countries, cities of 100,000 or more are expected to triple their built-up land area to 600,000 km<sup>2</sup> in the first three decades of this century."* By 2005, Asia had urban growth of 40% and Africa 38% which are the fastest global rates (Martine and Marshall, 2007). In addition, Green House Gasses (GHG) emissions are increasing Africa's temperature because it has more than the world average of GHG emissions especially in the Sahara area. (Field *et al.*, 2014). Furthermore, one of the least populated areas are located in northern Africa (Food and Agriculture Organization and World Bank population estimates., 2015). The built environment industry sector accounts for a third of the global energy consumption and generates 20% of man-made GHG emissions worldwide (World Business Council for Sustainable Development (WBCSD), 2015). This is why there is a need for energy efficiency measures to be taken regarding building performance and urban energy assessment targeting a new climate-responsive built environment.

The early design stage has gained a lot of attention recently especially in the area of urban sustainable simulation and optimization with regard to energy consumption. Urban geometry is formed by various elements each of which play a role in not only shaping the urban geometry but also affecting the microclimate on different scales of built environment.

The variation of these geometrical elements empowered the ability of using a parametric design approach in studying this relationship between urban geometry and energy consumption in the built environment.

Parametric design can be defined as the manipulation of different associated parameters to shape a form (Monedero, 2000). Thus, parametric urban design can be represented as a group of arranged buildings and urban geometrical variables that are shaped by scripted algorithms. This interpretation provides a different vision and capability for investigating urban design, geometry and performance (Schumacher, 2009a, 2009b). It has made urban design more interactive and responsive with good visualization outputs for either the design layout or its analytical data. The literature shows that there are different approaches to modelling and simulation at an urban scale (Hosney Lila and Lannon, 2017). The geometric variables tested for these studies included height, scale, orientation, urban voids, etc. In addition to variables, the aspects simulated in building performance were also covered in many ways. Some studies focused on a single aspect simulation such as energy-only simulations while others tried to combine two or more aspects of building performance such as studying the relationship between lighting performance and energy consumption and vice versa, or adding computational fluid dynamics (CFD) to the formula (Panão *et al.*, 2008; Bassett *et al.*, 2012; Dogan, Reinhart and Michalatos, 2012; Jones *et al.*, 2013; Sabry *et al.*, 2014; Trigaux, Allacker and Troyer, 2014; Taleghani *et al.*, 2015; Trigaux *et al.*, 2015; Nault, Rey and Andersen, 2016).

In regard to the tools used in these studies, there is a continuous development to help designers and architects conduct performance simulation and optimization at an urban scale. These tools are built using different approaches to provide a variety of functionality needed for each simulation or optimization study. Some tools are standalone software that carry out modelling, simulation and visualization tasks while others form a full suite designed only for simulation and optimization processes (© ENVI-MET GmbH *et al.*, 2016; U.S. Department of Energy's (DOE), 2016; Simulation Research Group, 2017). Yet other tools are mainly plug-ins that provide a link between simulation engines, that carry out the calculations, and modelling platforms. This link enables designers to visualise and analyse their results within the same software suites they are using to model their projects (Lagios, Niemasz and Reinhart F, 2010; Jakubiec and Reinhart, 2011; Reinhart *et al.*, 2013; Fonseca *et al.*, 2016; Reinhart, 2017). Other tools widened this spectrum of integrative simulation by creating open-source software for comprehensive modelling simulation (Sadeghipour and Pak, 2013). Adding to the mix, some studies have merged evolutionary solvers also known as genetic algorithms to the process of optimization (Rutten, 2013; Naboni, 2014; Yi and Kim, 2015; Calcerano and Martinelli, 2016).

The literature illustrates the potential of analysis tools and the usefulness of their integrative parametric approach. However, only a limited number of studies have investigated this holistic approach using these tools and explored the relative importance of the basic geometrical variables on energy consumption and thermal performance of the built environment at an urban scale. One of the recent tools that enabled more interaction with this holistic approach is the ladybug tools package (Sadeghipour and Pak, 2013). This package of tools covers different aspects of the built environment performance and at different scales. Also, it is based on the Rhinoceros/Grasshopper parametric modelling platform (McNeel, 2014; Scott Davidson, 2017). This study was conducted using these tools to add daylight illuminance sensitivity to the modelling of energy consumption for thermal comfort in residential context.

## Objective

This study aims to investigate the limits and opportunities of a framework for conducting a holistic analysis with ladybug tools, and to run a sensitivity analysis for geometrical variables.

The research quantified the effect of each geometrical variable on thermal performance and the change of consumption patterns due to the change in these variables on the energy consumption used in cooling and heating in hot arid zones. Furthermore, the study explored the correlation between lighting performance and controls and their effect on energy consumption and looked for more verification for this relationship by using standard recommended materials.

## Methodology

This study is a part of an ongoing research about holistic approach of optimization on neighbourhood scale. It looks into framing the impact of different urban geometrical variables besides investigating the relationship between thermal balancing energy consumption and the consideration of lighting control systems. Understanding this relationship will provide better recognition of built environment performance and its simulation. For this simulation, the dependant parameters is the urban geometrical variables while the energy performance outcome acts as the independent parameters.

The study was conducted using the weather file of Aswan city in southern Egypt (24.0889° N, 32.8998° E) and the Egyptian Typical Meteorological Year (ETMY) weather. Aswan, which has a hot and dry climate to (Kottek et al., 2006), was selected because it is a target of Egyptian future urban growth (Egyptian Ministry of State for Administrative Development, no date). It also represents an important sustainable development node for Egypt hosting the high dam of the Nile as one of the oldest national development projects. There are governmental plans for its growth with a twin new city.

### *Geometrical parameters & thermal settings*

The sensitivity analysis was conducted on a nine-building grid in a simple urban configuration as shown in figure (2). The building in the middle of that configuration was analysed with the other 8 buildings acting as a typical context. The grid cell size is 23 by 23 metre as representation of the common size of land size in Egypt (El-deep, El-Zafarany and Sheriff, 2012) with building areas varies from 50% to 90% of each cell's area with a 10% differentiation for each group. In addition to scale, the height was a feature of geometrical variation in the study. Buildings' heights varied between 3.5 metres and 24.5 metres with variation of a 3.5 floor for each group. Moreover, the whole configuration is rotated by 45 degrees creating two groups. The analysed building has a 30% core-to-perimeter ratio. EnergyPlus(U.S. Department of Energy's (DOE), 2016) *midrise apartment zone programs* were chosen for the building zones with *apartment programs* for the perimeter zones and *corridor programs* for the core zones (Figure 1 and 2). All zones are conditioned with the default set of ideal air loads system for Heating, Ventilation and Air Conditioning (HVAC). This is an hourly energy simulation with a 10 minutes time step. The simulation studied zone energy use and zone gains and losses as an output. The cooling loads are calculated from the sum of sensible and latent heat that must be removed from each zone as the HVAC is assigned to the default Ideal Air Loads.



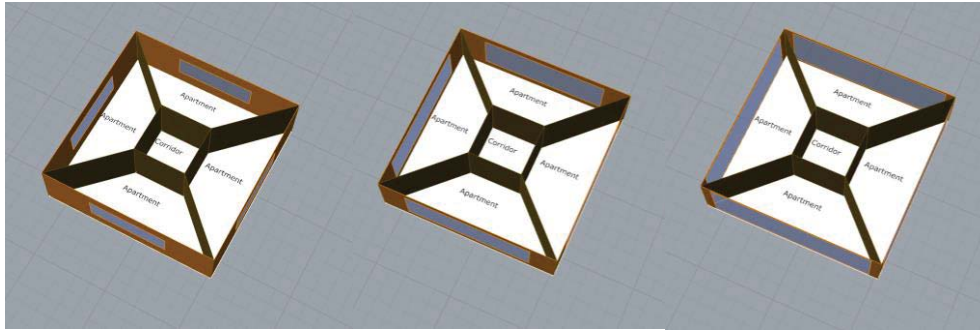


Figure 1. One floor example of different window to wall ratios and core to perimeter split and the programs assigned to different zones

Finally, the case study building has a fixed window to wall ratio for its 4 directions facades. The window to wall ratios (WWR) varied between 20%, 50% and 80% with. These variables are shown in Table 1.

Table 1. Geometrical parameters for the case study.

Geometrical Variables							
Height (metres)	3.5	7	10.5	14	17.5	21	24.5
Scale (built area ratios)	50%	60%	70%	80%	90%		
Window to Wall Ratio	20%	50%	80%				
Orientation (degrees)	0	45					

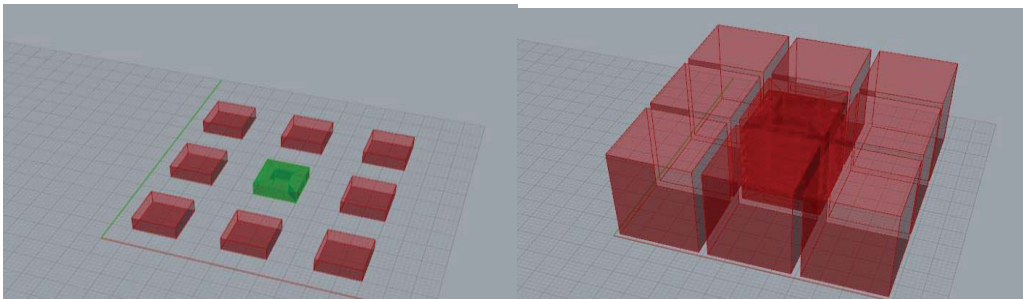


Figure 2. The tested geometrical model's examples. To the left: the first case for 20% WWR and 0 degrees' rotation with one 3.5 metres height floor and 50% built area of each grid cell. To the right: the last case in the same group (20% WWR & 0 degrees' rotation) with 7 floors, 24.5 metres total height and 90% built area.

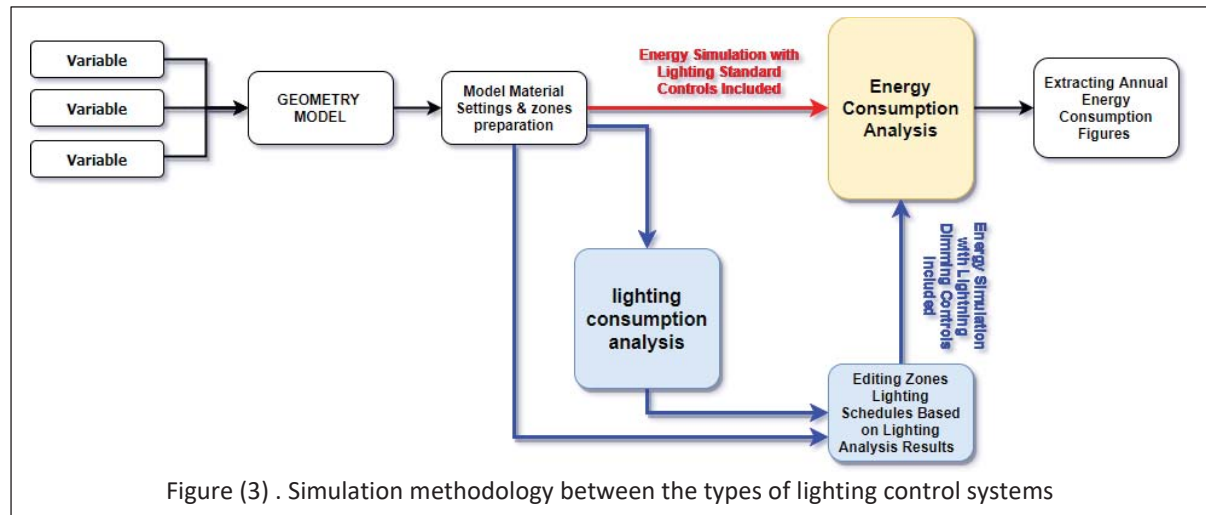
#### Daylighting analysis settings:

The main goal of combining daylight illuminance in the study was to try to reach a balance between the energy consumed for thermal comfort and lighting energy consumption of the zones. As with some of the dense configurations caused very little sun penetration which was very beneficial to the cooling energy consumption but on the other hand there was a need to know the effect this might have on lighting consumption.

For annual daylight analysis, each zone was divided into a mesh of 0.6 metre cells with one sensor point in its centre at 0.7 metre height from the floor. The lighting control system is auto dimming with switch off occupancy sensor with 300 lux target illuminance for each zone.

This algorithm cross-matched these geometrical variables, producing 210 different iterations. Thus, the study can be divided into 6 groups with 35 iterations each. These groups included two sets of orientations (0 and 45 degrees) and three sets of window to wall ratios (20%, 50% and 80%) with the full original variations of heights and building's scales. The total number of iterations was carried out twice: One run was conducted with basic on/off lighting

controls and the other run was conducted with dimming lighting controls based on annual daylighting profiles as mentioned earlier as shown in figure (3).



### Material parameters:

The study was then repeated twice with two different material settings. The first phase had all the afore-mentioned settings with literature review based material parameters, while the second phase used ASHREA 90.1-2010 (ANSI/ASHRAE/IESNA, 2010) material recommendation for the climate zone of the study as it was embedded in Energy Plus library for climate zone materials. For the first phase, The used material palette was adjusted based on studies conducted in the same geographical context (El-deep, El-Zafarany and Sheriff, 2012; Attia and Evrard, 2013). The material properties were fixed for all the iterations and designed based on the specification of the Chartered Institution of Building Services Engineers (CIBSE) Guide for environmental design (Butcher, 2006). Table 2 Shows the material parameters used in the study.

Table 2. Material parameters used in the study for both first & second phase.

FIRST PHASE MATERIALS			SECOND PHASE MATERIALS		
name	materials	U-Value	name	materials	U-Value
External Wall	<ul style="list-style-type: none"> <li>• CEMENT PLASTER</li> <li>• BRICK (EXPOSED)</li> <li>• CEMENT PLASTER</li> </ul>	3.10	ASHRAE 90.1-2010 EXTWALL MASS CLIMATEZONE 1	<ul style="list-style-type: none"> <li>• 1IN Stucco</li> <li>• 8IN CONCRETE HW RefBldg</li> <li>• 1/2IN Gypsum</li> </ul>	3.69
Internal Wall	<ul style="list-style-type: none"> <li>• CEMENT PLASTER</li> <li>• BRICK INTERIOR (EXPOSED)</li> <li>• CEMENT PLASTER</li> </ul>	5.29	INTERIOR WALL	<ul style="list-style-type: none"> <li>• G01a 19mm gypsum board</li> <li>• F04 Wall air space resistance</li> <li>• G01a 19mm gypsum board</li> </ul>	2.58
Internal Floor	<ul style="list-style-type: none"> <li>• CERAMIC-FLOOR-TILES</li> <li>• CEMENT-MORTAR(MOIST)</li> <li>• CONCRETE CAST(HEAVYWEIGHT)</li> <li>• GYPSUM-PLASTER</li> </ul>	1.43	INTERIOR FLOOR	<ul style="list-style-type: none"> <li>• F16 Acoustic tile</li> <li>• F05 Ceiling air space resistance</li> <li>• M11 100mm lightweight concrete</li> </ul>	1.44
External Roof	<ul style="list-style-type: none"> <li>• CEMENT-MORTAR(MOIST)</li> <li>• EXPANDED POLYSTYRENE (EPS)</li> <li>• CONCRETE, CAST (HEAVYWEIGHT)</li> </ul>	0.36	ASHRAE 90.1-2010 EXTROOF IEAD CLIMATEZONE 1	<ul style="list-style-type: none"> <li>• Roof Membrane</li> <li>• IEAD Roof Insulation R-14.76 IP</li> <li>• Metal Decking</li> </ul>	0.376
Window	<ul style="list-style-type: none"> <li>• CLEAR GLASS 12MM</li> </ul>	75	ASHRAE 90.1-2010 EXTWINDOW NONMETAL CLIMATEZONE 1	<ul style="list-style-type: none"> <li>• Fixed Window 5.84/0.25/0.11</li> </ul>	5.84

As for the second phase, ASHREA 90.1-2010 standard set materials were used for the envelop materials and for the adiabatic walls and floors the default material set offered by the ladybug tools.

## Results

### Show case:

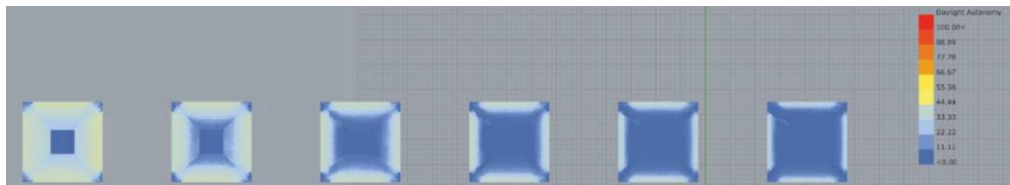


Figure (4). Daylight autonomy results illustration for 0 degrees rotation, 50% WWR, 6 floors height and 70% built area ratio showing the results of different zones. The floors order begins with the ground floor on the right up to the 5<sup>th</sup> floor on the left end

The results for each case was built to contain results for energy consumption aspects and daylighting results. This is shown in the example illustrated in Figures 4 and 5. The group results are summed up for each case. The example shown for illustration is an intermediate case with 0 degrees' rotation, 50% WWR, 6 floors height and 70% built area ratio.

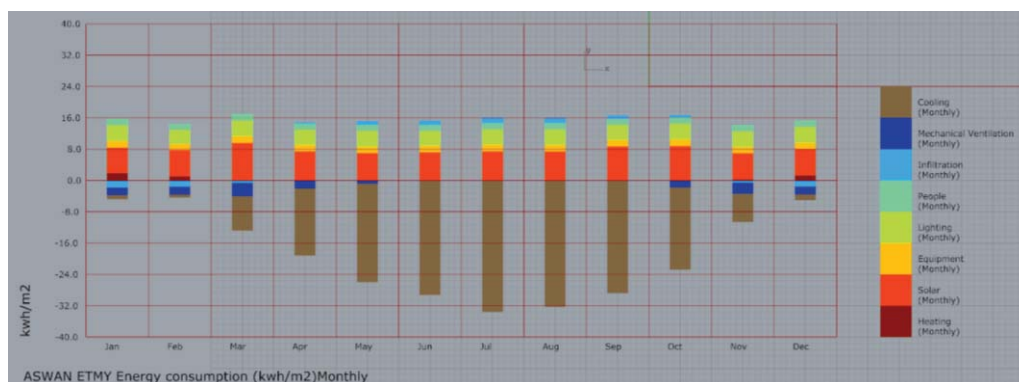


Figure (5). Total monthly consumption comparison for different aspects for the mentioned case in kWh/m<sup>2</sup>

The comparison is for cooling and lighting energy consumption with lighting dimming controls and with standard on/off lighting controls. Heating consumption varied between 1.7-8.5 kWh/m<sup>2</sup> for all the runs so it lacked significance to be added to the current study results as the cooling results have a much larger variance. The 6 groups are categorized by rotation angle and WWR for each with full heights and scale ranges as mentioned earlier. The categories are shown in Table 3.

Table 3. Groups' categories

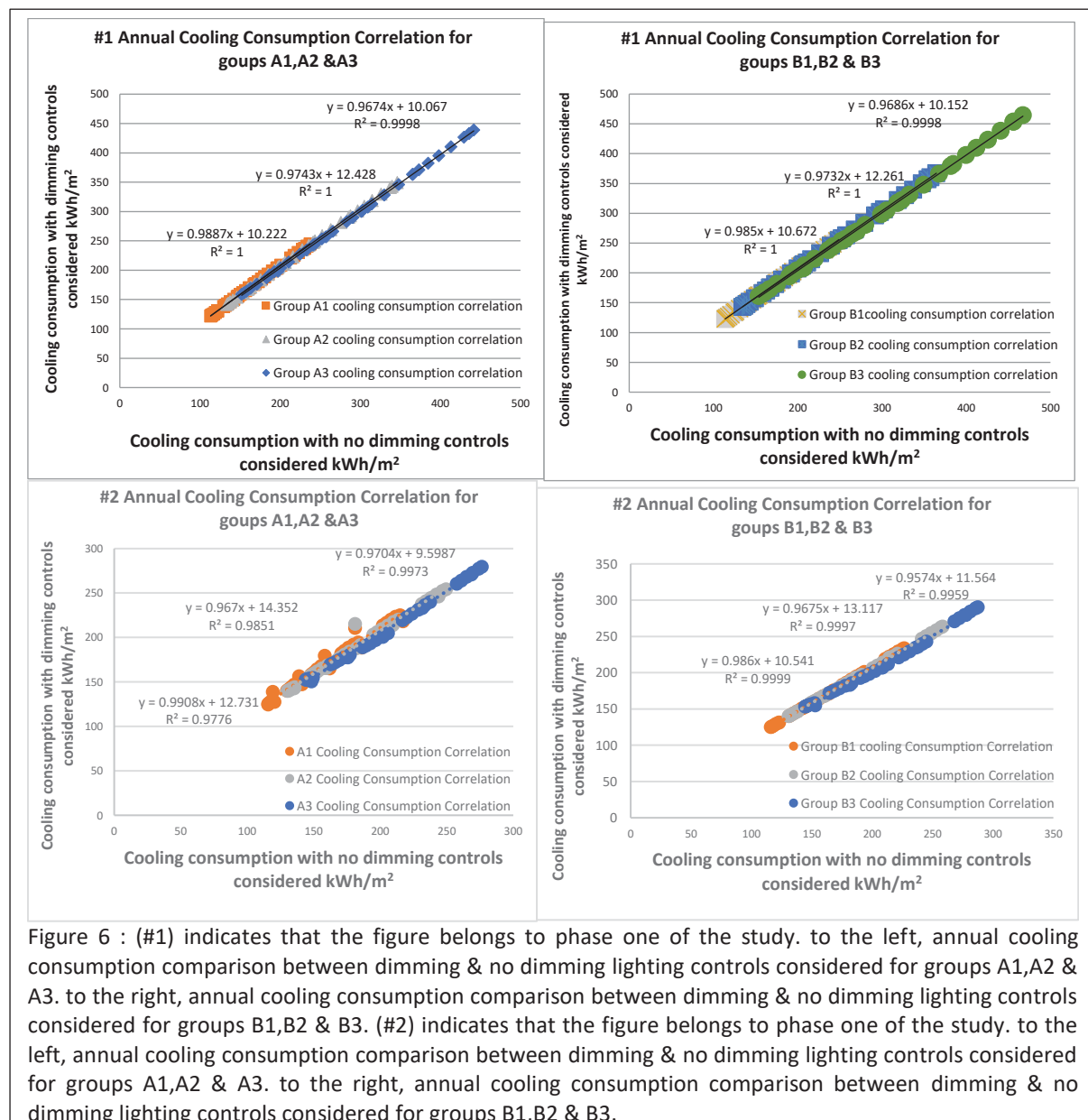
Group name	Rotation angle	WWR
A1	0	20%
A2	0	50%
A3	0	80%
B1	45	20%
B2	45	50%
B3	45	80%

### General lighting results remarks

The initial observation shows a direct effect on daylighting autonomy distribution in the first phase of the simulation. After the direct effect of WWR the scale and the context proximity also show a significant effect especially in the lower floors in the higher cases which leads to a rise in energy lighting consumption. It is important to mention that in the same case there

are no significant differences in lighting consumption per metre square either in the different floors or in the 5 different zones within the same floor. As for cooling consumption, the pattern of does not have the same baseline of applying the on/off controls as the one existed for lighting so it will be included in the groups' results discussions. The change of material in the second phase of the simulation did not change these patterns due to the lack of shading geometries, and the low number of bounces set by default in the analysis tool.

Lighting results and its pattern of change due to the variation of geometrical variables were discussed in detail for the first phase of the study in previous publication (Hosney Lila and Lannon, 2017). One of the significant results in that publication was the linear correlation in cooling consumption patterns when compared between the two lighting controls settings. As previously described, lighting analysis results were used to change the occupancy schedule for the energy consumption zones to look for the optimal balance between lighting and energy performance. This caused a significant change in results between the cooling consumption with the use of dimming lighting controls and the same consumption values when standard On/Off lighting controls where assigned. In the second phase of the study with



the change of material and the use of standardised materials, the correlation is not changed as it is shown in Figure 6. It is important to mention that changing the scale of the land plots will not affect this correlation due to the fixed core-to-perimeter ratio.

### **Variables relative importance**

#### **Heights:**

In the conducted study, there were 7 height variations. The results imply that there was a noticeable difference in the energy cooling consumption within the building. The study shows that the relationship between height and energy cooling consumption is that of a negative correlation in both phases. It could be said that this is due to the arid conditions of the specified zone. A comparison of the calculations of the extremities (highest and lowest blocks) showed that there is an 18 % difference in cooling consumption for the first phase of the study and nearly 4% for the second phase (Figure 7).

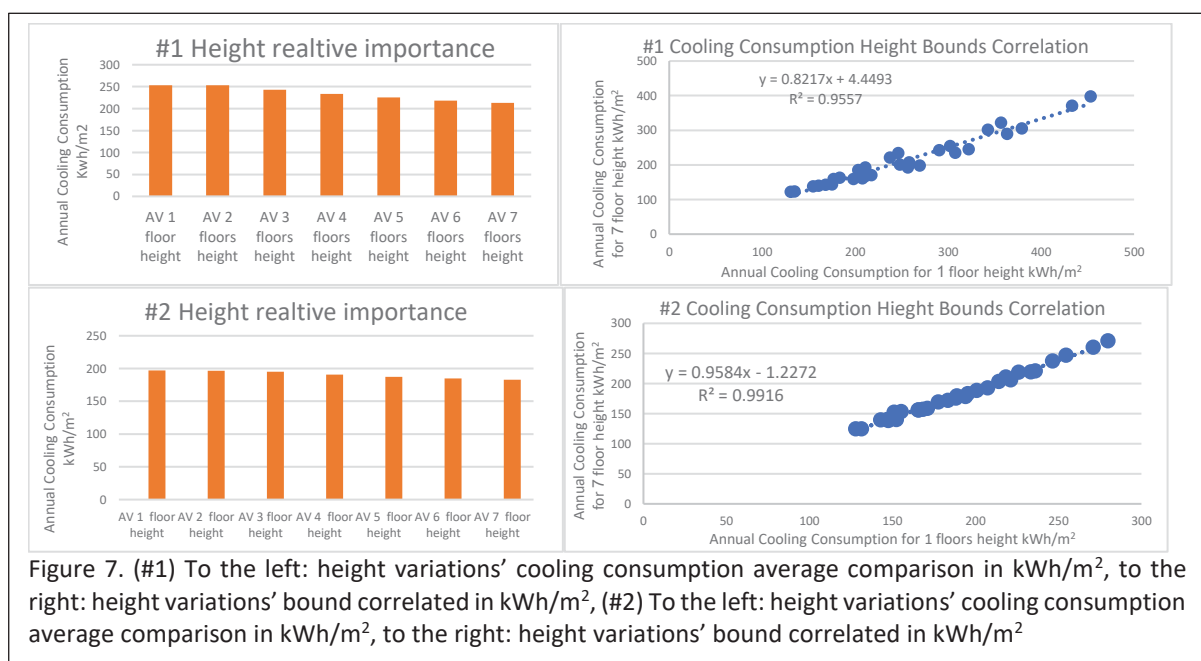
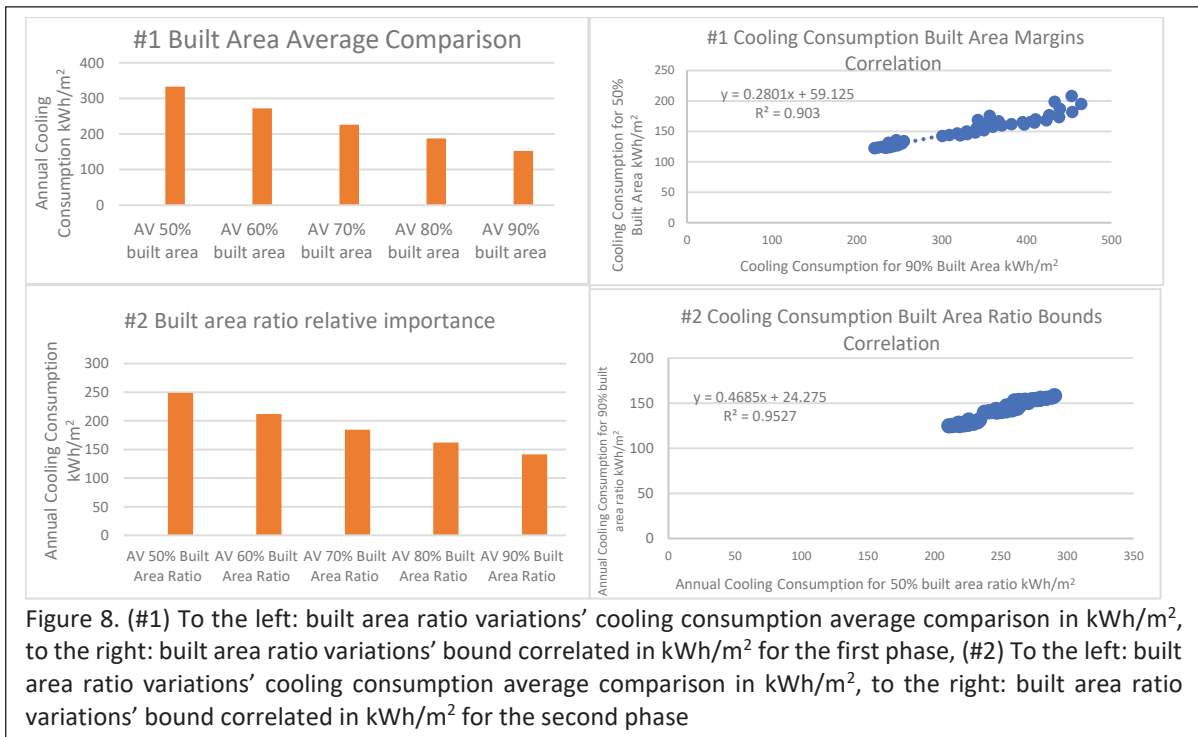


Figure 7. (#1) To the left: height variations' cooling consumption average comparison in kWh/m<sup>2</sup>, to the right: height variations' bound correlated in kWh/m<sup>2</sup>, (#2) To the left: height variations' cooling consumption average comparison in kWh/m<sup>2</sup>, to the right: height variations' bound correlated in kWh/m<sup>2</sup>

#### **Built area ratio:**

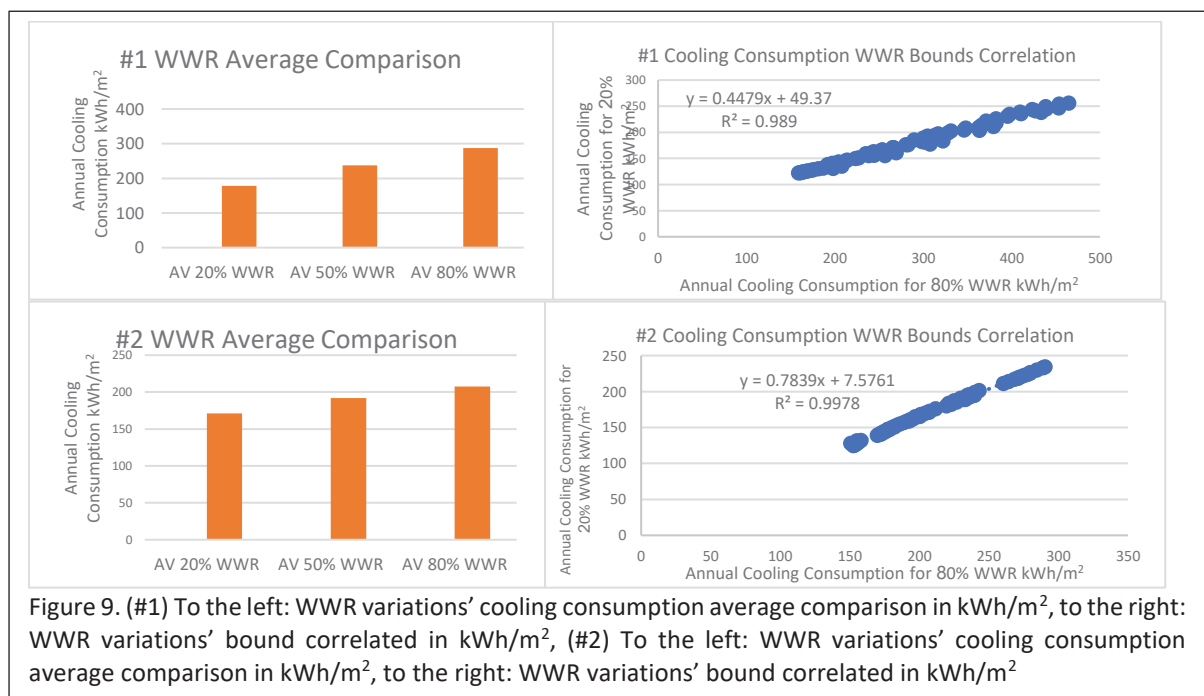
As mentioned before there were 5 built area ratio variations. The results imply that there was further change in the energy cooling consumption within the building. The study shows that the relationship between built area ratio and energy cooling consumption is a clear negative correlation as the denser the configuration the more prevention to sun penetration to the buildings. Therefore, cooling consumption is reduced heavily as shown in Figure 7. A comparison of the calculations of the bounds (most and least dense group configurations) showed that there is a 72 % difference in cooling consumption for the first phase and with the change of material for the second phase the difference reaches 54% of change between the bounds of the 5 groups (Figure 8).





#### WWR:

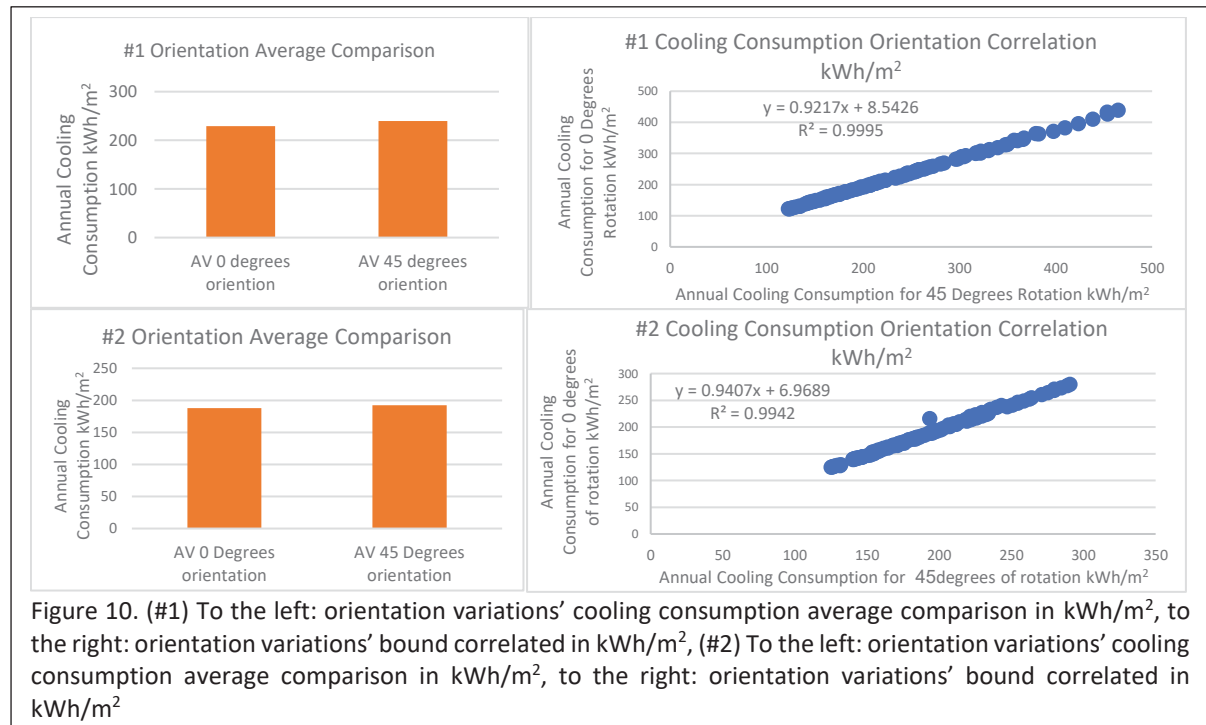
For WWR variations, the relationship with energy cooling consumption for the first phase is a positive correlation that becomes less steady when in the second phase. This can be caused by the climate zone chosen for the study. The difference in the energy cooling consumption is larger than what was shown for heights but still less than what is shown for built area ratios effect. The comparison between these variable limitations indicates that there is almost 66 % difference in cooling consumption for the first phase. But for the second phase this number decreases to 22% difference in consumption (Figure 9).





### Orientation:

There is a slight positive correlation for this variable, according to the results. Comparing the two variations for both phases, it can be argued that there is an 8% of energy cooling consumption difference that exists between the 2 different angles for the first phase while, for the second phase, it decreases to 6% difference in consumption between the two different angle groups (Figure 10).



### Conclusion

In addition to conducting a holistic analysis of geometrical variation and its effect on energy performance, this study used two sets of materials to assure the results of this sensitivity analysis and the variables' relative importance to energy consumption.

The results show that the thermal energy consumption has not significantly changed due to integrating the lighting control system variations to change the energy zones occupancy settings. With variation between 2%-5% change in cooling consumption correlation between using dimming in lighting control systems and using standard on/Off lighting controls, it can be argued that it is wise to delay the lighting analysis to a later stage of design specially if it is similar to the setting of this study model and limited to geometrical variables. It is important to note that the comprehensiveness of the capabilities of the Ladybug tools is still constrained by time limits when it comes to brute-force multi-iteration sensitivity analysis such as the ones used in this study. Merging different aspects of environmental building performance in the same platform and same study needs better optimized frameworks to enable this approach in the early design stage. Furthermore, this study quantified the relative importance of each of the studied geometrical variables and their effect on energy consumption in hot arid zones. Built area ratio was found to have the most significant impact on energy consumption for thermal performance while WWR followed the effect of Built area ratio in both phases of the study. Height variation was found to have a larger effect than Orientation on cooling energy consumption for midrise residential buildings in hot arid zones. The change of material settings between the two phases changed

the values and pattern of energy consumption results but still assured the lighting controls minimal effect on energy consumption and the relative importance of these variables in hot arid zones climatic conditions.

Further investigation is still needed regarding the relationship between geometrical variables and energy consumption and the integration of daylighting in different climatic conditions, material parameters and geometrical contexts. Although there are tools that can conduct comprehensive energy analysis, their capabilities regarding multi-iteration simulations are limited.

## References

- © ENVI-MET GmbH, E., Bruse, M., Huttner, S., Hofmeyer, J., Seeger, D. and Simon, H. (2016) *The Hitchhiker's Guide to ENVI-met*. Available at: <http://www.model.envi-met.com/hg2e/doku.php?id=files:downloadv4> (Accessed: 3 May 2016).
- ANSI/ASHRAE/IESNA (2010) *ANSI/ASHRAE/IESNA 90.1-2010, Energy Standard for Buildings Except Low-Rise Residential Buildings*. American Society of Heating, Refrigerating and Air-Conditioning Engineers. Atlanta, Georgia.
- Attia, S. and Evrard, A. (2013) 'Benchmark Models for Air Conditioned Residential Buildings in Hot Humid Climate', in *13th Conference of International Building Performance Simulation Association*. Chambry, France.
- Bassett, T., Lannon, S. C., Waldron, D. and Jones, P. J. (2012) 'Calculating the solar potential of the urban fabric with SketchUp and HTB2', in *Solar Building Skins*, . Bressanone, Italy.
- Butcher, K. (2006) 'CIBSE Guide A Environmental Design'. CIBSE Publications.
- Calcerano, F. and Martinelli, L. (2016) 'Numerical optimisation through dynamic simulation of the position of trees around a stand-alone building to reduce cooling energy consumption', *Energy and Buildings*, 112, pp. 234–243. doi: 10.1016/j.enbuild.2015.12.023.
- Dogan, T., Reinhart, C. and Michalatos, P. (2012) 'Urban daylight simulation calculating the daylight area of urban designs', in *Proceedings of SimBuild*. Madison, Wisconsin.
- Egyptian Ministry of State for Administrative Development (no date) *New Urban Communities Authority, 2016*. Available at: <http://www.newcities.gov.eg/english/default.aspx> (Accessed: 22 March 2017).
- El-deep, K., El-Zafarany, A. and Sheriff, A. (2012) 'Effect of building form and urban pattern on energy consumption of residential buildings in different desert climate.', in *PLEA 2012- 28th Conference, Opportunities, Limits & Needs Towards an environmentally responsible architecture*. Lima, Peru.
- Field, C., Barros, V., Dokken, D., Mach, K., Bilir, T., Chatterjee, M., Ebi, K., Estrada, Y., Genova, R., Girma, B., Kissel, E., Levy, A., MacCracken, S., Wilson, D. J. and Leslie L White, T. L. (2014) *Climate Change 2014 Impacts, Adaptation, and Vulnerability Part A: Global and Sectoral Aspects*. Cambridge University Press.
- Fonseca, J. A., Nguyen, T. A., Schlueter, A. and Marechal, F. (2016) 'City Energy Analyst (CEA): Integrated framework for analysis and optimization of building energy systems in neighborhoods and city districts', *Energy and Buildings*. Elsevier B.V., 113, pp. 202–226. doi: 10.1016/j.enbuild.2015.11.055.
- Food and Agriculture Organization and World Bank population estimates. (2015) *World Development Indicators / DataBank*. Available at: <http://databank.worldbank.org/data/reports.aspx?source=2&type=metadata&series=EN.POP.DNST> (Accessed: 15 March 2017).
- Hosney Lila, A. M. and Lannon, S. (2017) 'A parametric sensitivity analysis of the impact of built environment geometrical variables on building energy consumption', in *PLEA*. Edinburgh, UK.
- Jakubiec, J. A. and Reinhart, C. F. (2011) 'DIVA 2.0: Integrating daylight and thermal simulations using rhinoceros 3D, DAYSIM and EnergyPlus', in *Proceedings of Building Simulation 2011: 12th Conference of International Building Performance Simulation Association*, pp. 2202–2209.
- Jones, P. J., Lannon, S. C., Li, X., Bassett, T. and Waldron, D. (2013) 'Intensive building energy simulation at early design stage', in *13th International Conference of the International Building Performance Simulation Association*. Chambéry, France: International Building Performance Simulation Association (IBPSA), pp. 862–869.
- Kottek, M., Grieser, J., Beck, C., Rudolf, B. and Rubel, F. (2006) 'World map of the Köppen-Geiger climate classification updated', *Meteorologische Zeitschrift*, 15(3), pp. 259–263. doi: 10.1127/0941-2948/2006/0130.
- Lagios, K., Niemasz, J. and Reinhart F, C. (2010) 'Animated Building Performance Simulation ( Abps ) – Linking Rhinoceros / Grasshopper With Radiance / Daysim', *conference proceedings of SimBuild 2010*, (August), p. 7.
- Martine, G. and Marshall, A. (2007) 'UNFPA State of world population 2007: unleashing the potential of urban

growth', in *State of world population 2007: unleashing the potential of urban growth*. UNFPA.

McNeel, R. (2014) 'Rhinoceros 5'.

Monedero, J. (2000) 'Parametric design: a review and some experiences', *Automation in Construction*, 9, pp. 369–377.

Naboni, E. (2014) 'Integration of Outdoor Thermal and Visual Comfort in Parametric Design', in *30th International PLEA Conference*, pp. 1–10.

Nault, E., Rey, E. and Andersen, M. (2016) 'A Multi-Criteria Decision-Support Workflow for Early-Stage Neighborhood Design based on Predicted Solar Performance', in *PLEA 2016, 36th International Conference on Passive and Low Energy Architecture. Cities, Buildings, People: Towards Regenerative Environments*. Los Angeles, USA.

Panão, O., N. M. J., Gonçalves, H. J. P. and Ferrão, P. M. C. (2008) 'Optimization of the urban building efficiency potential for mid-latitude climates using a genetic algorithm approach', *Renewable Energy*, 33, pp. 887–896. doi: 10.1016/j.renene.2007.04.014.

Reinhart, C. (2017) *Daysim*.

Reinhart, C. F., Dogan, T., Alstan, J. J., Rakha, T. and Sang, A. (2013) 'Umi - an Urban Simulation Environment for Building Energy Use, Daylighting and Walkability', *Proceedings of BS2013: 13th Conference of International Building Performance Simulation Association*, pp. 476–483.

Rutten, D. (2013) 'Galapagos: On the Logic and Limitations of Generic Solvers', *Architectural Design*, March, pp. 132–135. doi: 10.1002/ad.1568.

Sabry, H., Sherif, A., Gadelhak, M. and Aly, M. (2014) 'Balancing the daylighting and energy performance of solar screens in residential desert buildings: Examination of screen axial rotation and opening aspect ratio', *Solar Energy*, 103, pp. 364–377. doi: 10.1016/j.solener.2014.02.025.

Sadeghipour, M. R. and Pak, M. (2013) 'Ladybug: a Parametric Environmental Plugin for Grasshopper To Help Designers Create an Environmentally-Conscious Design', in *13th Conference of International Building Performance Simulation Association*. Chambéry, France, pp. 3129–3135.

Schumacher, P. (2009a) 'Parametric Patterns', *Architectural Design*, November, pp. 28–41. doi: 10.1002/ad.976.

Schumacher, P. (2009b) 'Parametricism: A New Global Style for Architecture and Urban Design', *Architectural Design*, July, pp. 14–23. doi: 10.1002/ad.912.

Scott Davidson (2017) *Grasshopper - algorithmic modeling for Rhino*. Available at: <http://www.grasshopper3d.com/> (Accessed: 17 June 2017).

Simulation Research Group, U. S. D. O. E. (2017) *DOE-2 | Simulation Research*. Available at: <http://simulationresearch.lbl.gov/projects/doe2> (Accessed: 14 June 2017).

Taleghani, M., Kleerekoper, L., Tenpierik, M. and van den Dobbelsteen, A. (2015) 'Outdoor thermal comfort within five different urban forms in the Netherlands', *Building and Environment*, 83, pp. 65–78. doi: 10.1016/j.buildenv.2014.03.014.

Trigaux, D., Allacker, K. and Troyer, F. De (2014) 'A simplified approach to integrate energy calculation in the Life Cycle Assessment of neighbourhoods', in *30th International PLEA Conference, Volume: Sustainable habitat for developing societies*. Ahmedabad, India.

Trigaux, D., Oosterbosch, B., Allacker, K. and De Troyer, F. (2015) 'A design tool to optimize solar gains and energy use in neighbourhoods', in *PLEA 2015-Architecture in (R) Evolution*. Bologna, Italy: Ass. Building Green Futures, p. 305.

U.S. Department of Energy's (DOE) (2016) *EnergyPlus™*. Available at: <https://energyplus.net/> (Accessed: 10 May 2016).

World Business Council for Sustainable Development (WBCSD) (2015) *Low Carbon Technology Partnerships initiative (LCTPI) - Action Plan*.

Yi, Y. K. and Kim, H. (2015) 'Agent-based geometry optimization with Genetic Algorithm (GA) for tall apartment's solar right', *Solar Energy*, 113, pp. 236–250. doi: 10.1016/j.solener.2014.11.007.

# Predicting moisture risks in solid walls retrofitted with internal insulation. The pros and cons of WUFI hygrothermal modelling.

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**Abstract:** This paper examines the pros and cons of using the hygrothermal modelling tool WUFI Pro to predict moisture risks when internal wall insulation (IWI) is retrofitted to traditional, masonry solid wall dwellings. Up to 3.4 million solid wall homes in the UK will need IWI installed if the UK is to meet its legally binding commitment to reduce greenhouse gases by 80% by 2050. Unfortunately, retrofitting IWI to masonry solid walls can introduce moisture risks – a problem exacerbated by the limited research and understanding of hygrothermal issues in the UK's traditional solid wall buildings. It is essential to be able to predict moisture risks prior to installing IWI. This is possible with WUFI Pro but what are the challenges faced in achieving reliable results in real-world situations? This research is a case study of an Edwardian London terrace house retrofitted with IWI to the front wall. Relative Humidity (RH) and temperature were monitored within the wall for three years. The measured data was compared with a WUFI Pro model of the wall. The research cautiously suggests that there are no long-term moisture risks in the wall. However, the most certain findings relate to the modelling tool. WUFI Pro cannot be used with confidence to predict moisture risks unless used in conjunction with WUFI 2D and unless the original wall's material properties are physically tested and comprehensive, site-specific climate data is collected. This paper summarises practical findings for the benefit of WUFI practitioners.

**Keywords:** Internal wall insulation, solid wall dwellings, WUFI Pro, hygrothermal modelling, moisture risk

## Introduction

To alleviate climate change, the UK is committed to an 80% reduction in greenhouse gas emissions on 1990 levels by 2050 (DECC, 2015). An estimated 8% of all UK emissions come from solid wall dwellings and reducing emissions from these properties is essential. To this end, the space-heating energy use of all solid wall properties needs to be substantially reduced from a UK average of 121kWh/m<sup>2</sup>/yr to around 48kWh/m<sup>2</sup>/yr. This will require wall insulation with low U-Values of 0.15-0.18W/m<sup>2</sup>K (Khayatt, 2016). Conservation restrictions and aesthetic concerns may prevent the use of external wall insulation in up to 3.4 million solid wall dwellings, necessitating IWI in these properties (Khayatt, 2016).

Unfortunately, IWI can lead to moisture building up within a solid wall. IWI renders the original masonry cooler, increasing the likelihood of interstitial condensation within the wall whilst also hindering the wall's ability to dry out to the inside (Kunzel, 1998a). This additional moisture can degrade the building fabric through rot, corrosion and frost damage; impact human health by exposing occupants to mould; and reduce thermal performance (May, 2005; Sedlbauer, 2001; Sedlbauer and Kunzel, 2006).

In the UK, there is limited research concerning hygrothermal issues in traditional buildings and there is a huge gap between research and practice (May and Rye, 2012). A literature review by Khayatt (2016) revealed four key recommendations for limiting moisture risks with IWI: minimise rain penetration from outside, minimise vapour penetration from inside, limit insulation thicknesses to U-Values above 0.35W/m<sup>2</sup>K and ensure the wall can 'breathe' – that it can dry to both the outside and inside. These recommendations were compared with practice on 44 recent high-energy efficiency retrofit projects in the UK. Only one project complied with all four recommendations. This blindness cannot continue if 3.4 million solid wall dwellings are to receive IWI by 2050. Otherwise extensive damage could be unwittingly introduced to these historic properties,

their occupants' health could be affected and energy-efficiency savings not realised. It is essential therefore to have practical working solutions and to be able to predict moisture risks on a case-by-case basis prior to IWI being retrofitted.

Currently, mainstream guidance in the UK for assessing moisture risks is based on the Glaser Method outlined in BS 5250 (Little and Arregi, 2016). This is entirely inappropriate for solid wall dwellings because it fails to take account of the fact that some material properties change with moisture content and it considers only the movement of water as a vapour, not as a liquid (BSI, 2012:pv). Standards and guidance are now moving towards dynamic simulations (Smith, 2017) outlined in the standard IS EN 15026:2007. These are considered much more reliable, allowing for changing climatic conditions and material properties and taking account of the storage and movement of moisture in both vapour and liquid form (Sanders, 2015). WUFI Pro is a German hygrothermal modelling tool, which conforms to IS EN 1026:2007 (Fraunhofer IBP, 2015a). It is aimed at real-world situations and has been validated over 20 years through full-scale field tests on different building elements (Straube and Schumacher, 2006).

In the UK and Ireland, researchers have used WUFI Pro to examine the viability of different IWI strategies (Little and Arregi, 2013); test different orientations/locations (Marincioni, 2015); test parameters such as brick properties (Browne, 2012) and examine the junction between external walls and ground floors (Little and Arregi, 2016). However, there is almost no research comparing WUFI Pro modelling with measured results. The author found one study in Glasgow (Baker and Phillipson, 2015) and none involving walls retrofitted with IWI to very low U-Values. What therefore are the challenges of using WUFI Pro in a real-world situation to predict moisture risks?

This paper is based on a case study of a two-storey Edwardian terrace house with 9" brick solid walls (Hawthorn Road), which was refurbished in 2010 to achieve a measured space-heating energy use of 52kWh/m<sup>2</sup>/yr. Hawthorn Road's front wall was internally insulated to a U-Value of 0.15W/m<sup>2</sup>K with breathable materials: sheep's wool insulation, an intelligent vapour control layer (VCL), woodfibre board and a lime plaster finish. This breathable strategy complies with all of the recommendations except insulation thicknesses, achieving a far lower U-Value than is considered compatible with solid wall IWI.

Measured data was collected and compared with a WUFI Pro model of Hawthorn Road's front wall. The primary aim was to establish whether there were moisture related problems within the wall. Is the breathable IWI strategy working? Are low U-Values achievable after all? To this end, the WUFI Pro model hugely informed and expanded on the measured data. However, the most certain findings related to the difficulties encountered in producing a reliable WUFI Pro model. This paper focuses on those findings.

## **Methodology**

### ***Measured Data***

Croxford (2013, 2015) measured temperature and RH using battery operated HOBO HO8 Onset loggers located in the front wall, rear bedroom and living room. Data was collected from three 'Brick HOBOS' – installed on the inside face of the front wall's brick – from August 2012 to December 2013. Data was collected from the room HOBOS and 'Insulation HOBO' – installed within the front wall's insulation – from the end of refurbishment in January 2011 through to December 2013. Data was collected at either five-minute or thirty-minute intervals. See Figure 1.



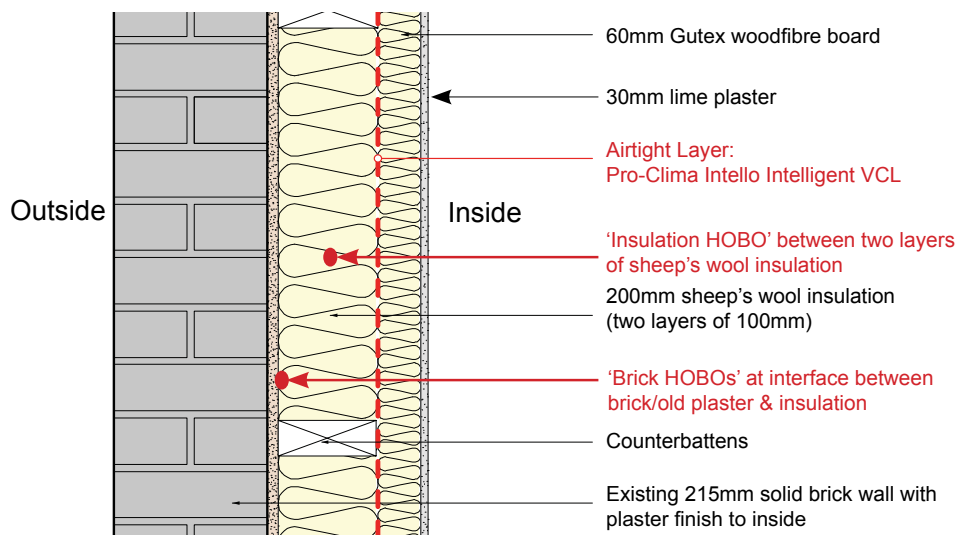


Figure 1. Hawthorn Road's refurbished front wall showing wall build-up and location of HOBOs

The Brick HOBO datasets were averaged to create one dataset. All the HOBO's data was hourly averaged to align with WUFI Pro and external climate datasets. The author produced graphs from the hourly-average data sets, running from January 2011 through to December 2013. (For legibility, the Brick HOBO graph also included weekly averages.) These graphs are hugely informative because they show how temperature and RH change within the wall over time. RH peaks and troughs can be quickly seen and year-on-year comparisons made. The length of time RH exceeds certain levels can also be evaluated.

The extent of data loss and overall reliability of the HOBOs was examined and two potential problems identified. Firstly, the in-wall HOBOs are inaccessible and could not be calibrated annually as recommended (Onset, n.d.a.). They may have lost accuracy over time – especially the sole Insulation HOBO which was exposed to very high RH's (>90%) for a long time and whose measurements could not be averaged against other insulation HOBOs. Secondly, the Brick HOBOs did not monitor the critical first eighteen months after the refurbishment.

### **WUFI Pro Model**

A WUFI Pro model of Hawthorn Road's front wall was created using data inputs described below. The model's calculation period ran from January 2011 to December 2013 to align with the measured data. WUFI Pro can provide 'courses' showing how temperature and RH change over the calculation period. Two WUFI 'monitors' were placed in equivalent locations to the HOBOs and their resulting courses overlaid onto the measured data graphs. This simple visual comparison gave a clear picture of how closely the WUFI model aligned with reality in the two locations.

The data inputted into the model was then adjusted and the calculation re-run until a better visual alignment between the WUFI courses and HOBO graphs was achieved. For example, radiation data was added because the RH levels at the brick/old plaster interface appeared higher in the WUFI model and exhibited less summer drying than reality (WUFI model 2). The brick's short wave radiation absorptivity (percentage of solar radiation the brick absorbs) was increased for the same reason (WUFI 5). The wall's assumed starting RH was increased to reflect anecdotal evidence that the internal lime plaster had taken weeks to dry out (WUFI 4). Material properties found by other researchers to be significant were



also adjusted (WUFI 6-8). This was an iterative process, which took several weeks and over 40 iterations. Following this, the best WUFI Pro model was examined more extensively to better understand how, why and when moisture moved through the wall. A moisture risk assessment was made using five criteria set out below.

#### *Data Inputted into WUFI Pro Model*

WUFI Pro has nine 'dialog boxes' concerning the wall, its location and the ambient conditions. In the first - "Wall Assembly" - the wall was modelled to reflect the dimensions of Hawthorn Road's front wall with the mortar crudely modelled as a central vertical band within the brick.

In the second - "Material Properties" - five basic properties and three optional 'hygric extensions' are required for each material. All the properties of the Gutex woodfibre board and the Intello VCL were known with certainty – these were sourced from WUFI's own database of materials. Properties for the other materials were sourced as follows. Brick: Basic properties came from Browne's (2012) Fletton Brick, because this is a red brick used extensively in the area in the early C20th. However, in hindsight this choice was inappropriate as the Fletton is an old engineering brick not typically used as a facing brick (Bradshaw, 2017). No hygric extensions were inputted at first for the brick. Mortar, old plaster and new lime plaster: properties for 'lime plaster stucco' within the WUFI materials database were used, as this lime plaster had been identified by Browne (2012) as producing worst case scenarios and hygric extension data was available. Thermafleece sheep's wool insulation: some basic properties were obtained from the manufacturer (Second Nature, n.d.) but porosity and the hygric extensions came from 'Swisswool', the only sheep's wool insulation within the WUFI database.

Default values were used for "orientation and rain exposure" and "surface transfer coefficients" because the wall is vertical, in a sheltered location and the climate file lacked radiation data. Similarly, default values were inputted for "initial conditions" in which the RH and temperature within the wall at the start of the WUFI calculation period are defined. As noted above, the "calculation period" ran from January 2011 to December 2013. All heat/moisture transport mechanisms were included under "calculation numerics" so that the model could reflect reality as closely as possible.

For "external climate", data on temperature, RH, wind direction and speed, rain and global radiation were obtained from three London weather stations and amalgamated to create one data set. (Unfortunately, no one station collected all the parameters required.) No radiation data was included at first because both global and diffuse radiation are required and the latter is only monitored at two Met Office stations in the UK – in Cornwall and Scotland. In subsequent models, the author produced a data set for diffuse radiation using the EU's Photovoltaic Geographical Information System (PGIS). This database provides estimated hourly averaged global and diffuse radiation data for any location within Europe (JRC, 2015). Using PGIS data for Hawthorn Road's location, the author calculated the ratio of global to diffuse radiation for each hour of every month. These hourly ratios were then used to estimate Hawthorn Road's diffuse radiation from the local weather stations' measured global radiation. For the ninth dialog box - "internal climate" - a dataset was created using three years of temperature and RH measurements from the upstairs rear bedroom. Unfortunately the bedroom adjacent to the front wall had not been monitored. However anecdotal evidence suggests conditions within these two rooms were both similar and stable.

## Results and Analysis

This paper asks two questions: Did the WUFI model provide the information required to predict all moisture risks within the front wall? Are the results of the WUFI model reliable?

### ***Usefulness of WUFI Pro Model***

To determine whether WUFI Pro's information is useful, one needs to know what to look for. An extensive review of academic papers and WUFI's advice concluded with five criteria for assessing in-wall moisture risks (Khayatt, 2016). These criteria address general good practice, mould growth, frost damage and thermal performance.

*Criterion 1: Moisture must not accumulate year on year and RH should not exceed 80% for longer than six months in any part of the wall.* WUFI Pro can provide courses showing RH levels in any part of the wall and moisture content levels in the wall's individual materials over time. The model can be run over many years until year on year equilibrium is observed.

*Criterion 2: RH and temperature isopleths must stay below limits to mould growth.* Isopleths are diagrams, which plot simultaneous RH and temperature conditions and then illustrate for how long conditions conducive to mould growth are present. WUFI Pro can provide Isopleths for any part of the wall, identifying whether mould might be a problem. Further investigation can be carried out using the add-on WUFI Bio (Fraunhofer IBP, n.d).

*Criterion 3: Moisture content within wood and wood-based materials must not exceed 20% mass of moisture for a prolonged period of time.* Moisture levels in all materials can be calculated. However WUFI Pro cannot be used for complex elements such as floor junctions, joist ends and window frames. Little and Arregi (2013) identified situations where a solid wall with IWI appears fine in WUFI Pro but exhibits unsafe moisture contents at joist ends when modelled with the two-dimensional software, WUFI 2D. WUFI 2D modelling is therefore essential.

*Criterion 4: Moisture content of brick must not exceed 'critical degree of saturation' at times when temperatures cross 0°C.* This is the level of moisture content within a material above which frost damage is likely (Straube et al, 2010). Whilst WUFI Pro can provide simultaneous temperature and moisture content information, unfortunately there is very little data on critical degrees of saturation for UK bricks (WUFI administrator, 2009).

*Criterion 5: The wall U-Value must not exceed the designed value for prolonged periods of time.* WUFI Pro can provide thermal transmission analysis showing the wall's moisture-dependent, changing U-Values over time.

In summary, a detailed understanding of the wall's moisture behaviour and all but one of the five criteria can be assessed if WUFI Pro is used in conjunction with the add-on WUFI Bio and the brick's critical degree of saturation is known. However, to assess moisture risk in elements such as floor junctions and joist ends, further work in WUFI 2D is required.

### ***Reliability of WUFI Pro Model***

The WUFI Pro model was used alongside the measured results to assess moisture levels and risks within the front wall. The results suggest that the wall was worryingly damp during the first two years after refurbishment but that it did dry out resulting in no long-term problems – although this finding is limited because no WUFI 2D modelling was undertaken (Khayatt, 2016).

However the author has some concerns regarding the reliability of the WUFI results. 'WUFI 5' - the model whose RH and temperature courses most closely aligned with the measured graphs still shows some divergence from reality (Figures 2&3). It is unlikely that

this divergence is solely due to potential inaccuracies in the measured data. As noted above, this paper does not question the accuracy of the underlying software. The issue is the quality of the data inputted into the model.

This section reflects on the four categories of data inputs which proved particularly challenging to obtain and which were critical to get right because they made a substantial impact on the WUFI results.

#### *External Climate*

As discussed above, external climate conditions were not measured at the property itself. The external climate file used in the WUFI Pro models combined climate data from three London stations. It is beyond the scope of this paper to ascertain whether the minor differences in climate conditions between the WUFI climate file and reality had an impact. However, the significance of radiation is clear. In Figures 2&3, the only difference between the models WUFI 1 and WUFI 2 is the introduction of radiation data to the latter's climate file. Adding radiation data substantially reduces summer RH levels at both the brick/old plaster interface and within the insulation. The brick is drying out more to the outside - particularly in summer – leading to year-on-year reductions in RH levels.

Diffuse radiation data is difficult to obtain but the impact is too big to be ignored. This research made a crude approximation of diffuse radiation data, but whether this approach is sufficiently accurate for WUFI Pro's calculations is a big unknown and undermines confidence in the WUFI results.

#### *Surface Transfer Coefficients*

The only difference between WUFI 4 and WUFI 5 is the value of the brick's short-wave radiation absorptivity – the percentage of radiation, which the brick absorbs. This was increased from WUFI's default 0.6 in WUFI 4 to 0.9 in WUFI 5. The latter's RH course shows bigger summer troughs leading to steeper year on year reductions in moisture levels (Figures 2&3). The hike in radiation absorptivity increases the brick's ability to dry out – especially in summer resulting in summer RHs approximately 8% lower after a year or two. It is critical therefore to know the brick's short-wave radiation absorptivity with confidence.

#### *Initial Moisture and Temperature Conditions:*

These are the assumed conditions at the start of the WUFI Pro calculation period – measured by the Insulation HOB0 as 15°C and 85% RH in January 2011. The only difference between WUFI 3 and WUFI 4 are the initial conditions set at a default 20°C/80% and an approximated 15°C/90% respectively. The temperature quickly adjusts to ambient conditions, suggesting accuracy on temperature is not essential. However it takes two and a half years for the WUFI 3 and WUFI 4 RH courses to realign (Figures 2&3). This highlights the importance of running WUFI calculations over many years, especially as it cannot be possible to predict what a wall's RH levels will be on completion of a future refurbishment. It also highlights the need to keep the walls as dry as possible before and during refurbishment.

#### *Material Properties*

The precise properties of the brick, mortar, old plaster, sheep's wool and new internal plaster were not known and there is very little data on old UK materials, from which properties could be sourced. A number of changes were made to various brick properties in WUFI models 6a-f and the resulting impact on predicted RH levels at both monitor locations is dramatic. Table 1 details the property values used and Figures 4&5 illustrate their impact.

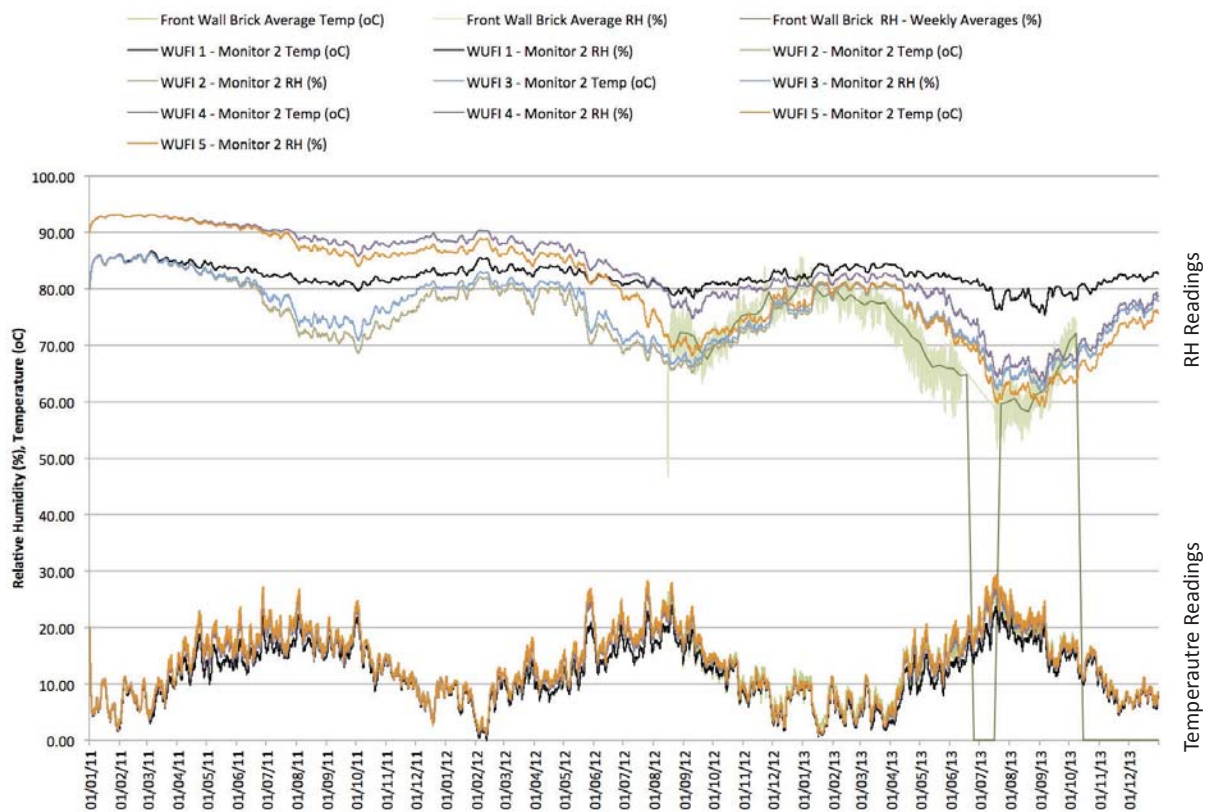


Figure 2: WUFI 1-5 results compared with Brick HOBO measurements – temperature and RH courses at brick/old plaster interface of front wall

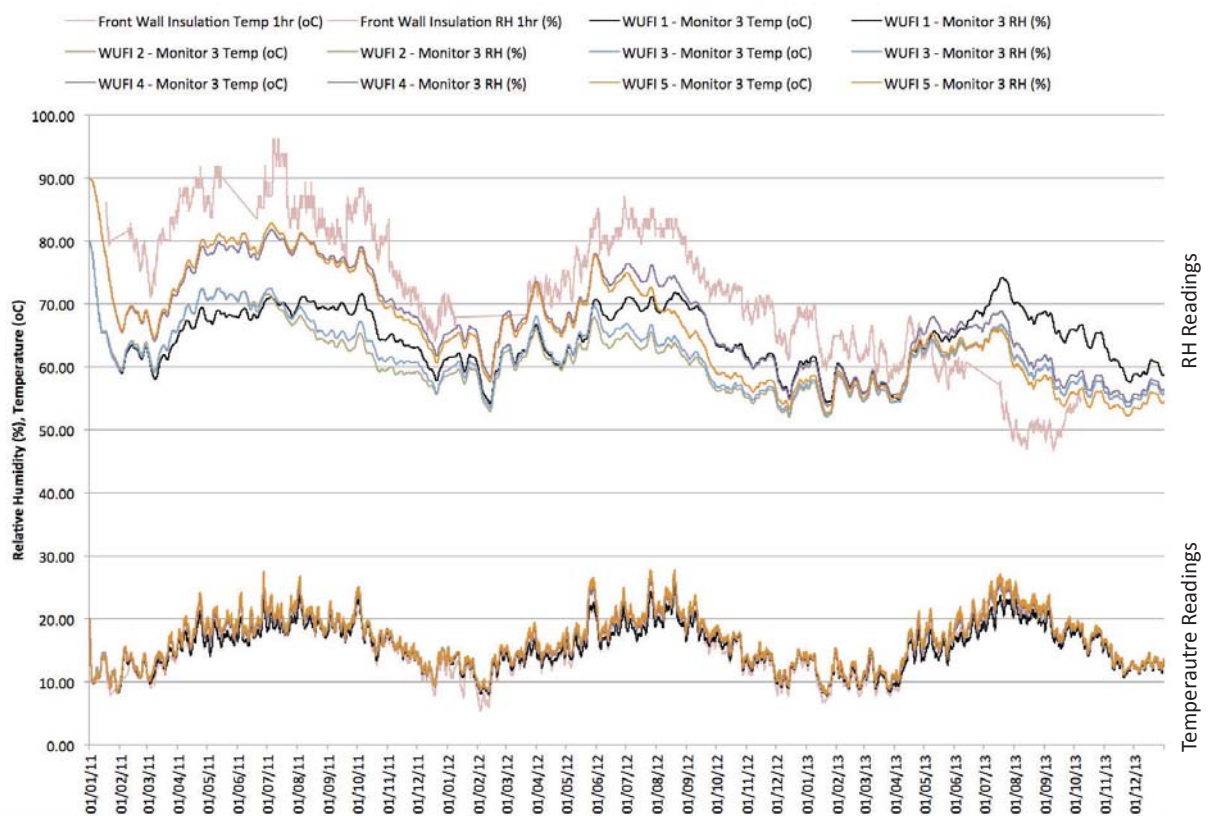


Figure 3: WUFI 1-5 results compared with Insulation HOBO measurements – temperature and RH courses within the front wall insulation

Table 1. Changes made to brick parameters in WUFI models 6a-f

Property	Value Inputted for Brick						
	Range in WUFI database (1)	WUFI 1& 5 (2)	WUFI 6a (2)	WUFI 6b	WUFI 6c	WUFI 6d	WUFI 6e&f (3)
<b>Basic Data</b>							
Bulk density ( $\text{kg/m}^3$ )	1560-2012	1740	1740	1979	1740	1740	1740
Porosity ( $\text{m}^3/\text{m}^3$ )	0.24-0.41	0.33	0.33	0.25	0.24	0.33	0.33
Specific Heat Capacity, dry ( $\text{J/kgK}$ )	794-1000	1000	1000	834	1000	1000	1000
Thermal conductivity, dry ( $\text{W/mK}$ )	0.393-0.962	0.47	0.47	0.9899	0.47	0.393	0.47
Water Vapour Diffusion Resistance Factor	10-45	16	16	45	16	16	16
<b>Hygic Extension</b>							
Reference Water Content ( $\text{kg/m}^3$ )	1.2-30	N/A	3.3	2.5	N/A	N/A	3.3
Free Water Saturation ( $\text{kg/m}^3$ )	82-369	N/A	278	82	N/A	N/A	278
Water Absorption Coefficient – A-value ( $\text{kg/m}^2 \sqrt{\text{s}}$ )	0.014-0.583	N/A	0.26	0.05	N/A	N/A	0.0011
1. Range given in Browne, 2012: Table 5 2. Brick properties and Hygic Extensions for Fletton Brick from Browne (2012) 3. Lowest A-value given by Little and Arregi (2013)							

WUFI 5 – which incorporates no hygic extensions – shows the closest alignment with the HOBO graphs. However it also exhibited suspicious results for the brick's moisture content. Essentially no rainfall appeared to penetrate the brick, which is highly unlikely. In addition, WUFI's estimation of the brick's water content was surprisingly low (Khayatt, 2016). Whilst ignoring the hygic extensions gave a good-looking result at first glance, it did not reflect reality. The hygic extensions are clearly important and should be used.

It is also interesting to compare WUFI 6a and 6e. Both of these models use Browne's (2012) values for a Fletton brick. The only difference is that the brick's water absorption coefficient (A-Value) is changed from Browne's  $0.26 \text{ kg/m}^2 \sqrt{\text{s}}$  in WUFI 6a to a much lower  $0.001 \text{ kg/m}^2 \sqrt{\text{s}}$  in WUFI 6e. WUFI 6a exhibits very high RH levels far removed from reality. WUFI 6e aligns much more closely with the HOBO graphs. However,  $0.001 \text{ kg/m}^2 \sqrt{\text{s}}$  is at the lowest limit of all A-values found by the author in literature. This value comes from Little and Arregi's (2013) proposed range and is lower than any of the 30 Bricks in the WUFI database, whose A-values range from  $0.014\text{-}0.583 \text{ kg/m}^2 \sqrt{\text{s}}$  (Browne, 2012).

Hawthorn Road's brick is an early C20th red facing brick whose true A-value could be one or two orders higher than that used in the WUFI 6e model. In addition, it is likely to be less dense and more porous than a hard Fletton brick. Clearly, other unidentified factors are at play here and ultimately the brick's properties need to be physically tested. Browne (2012) proposes a number of simple tests for measuring key material properties – but these tests cannot be carried out in situ. Samples of each material are required and will be destroyed during the testing process. This was not possible during the research, which was carried out long after the refurbishment was complete.



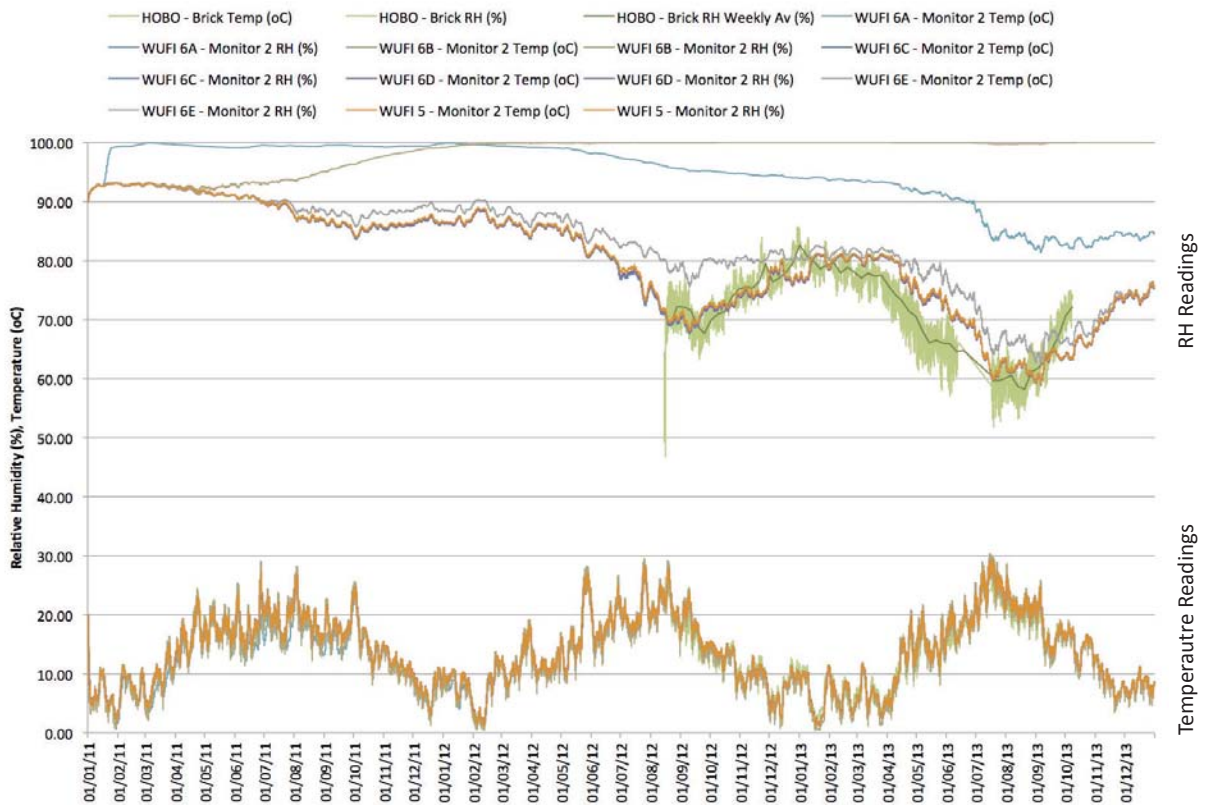


Figure 4: WUFI 5 and 6a-6f results compared with Brick HOBO measurements – Temperature and RH courses at brick/old plaster interface of front wall

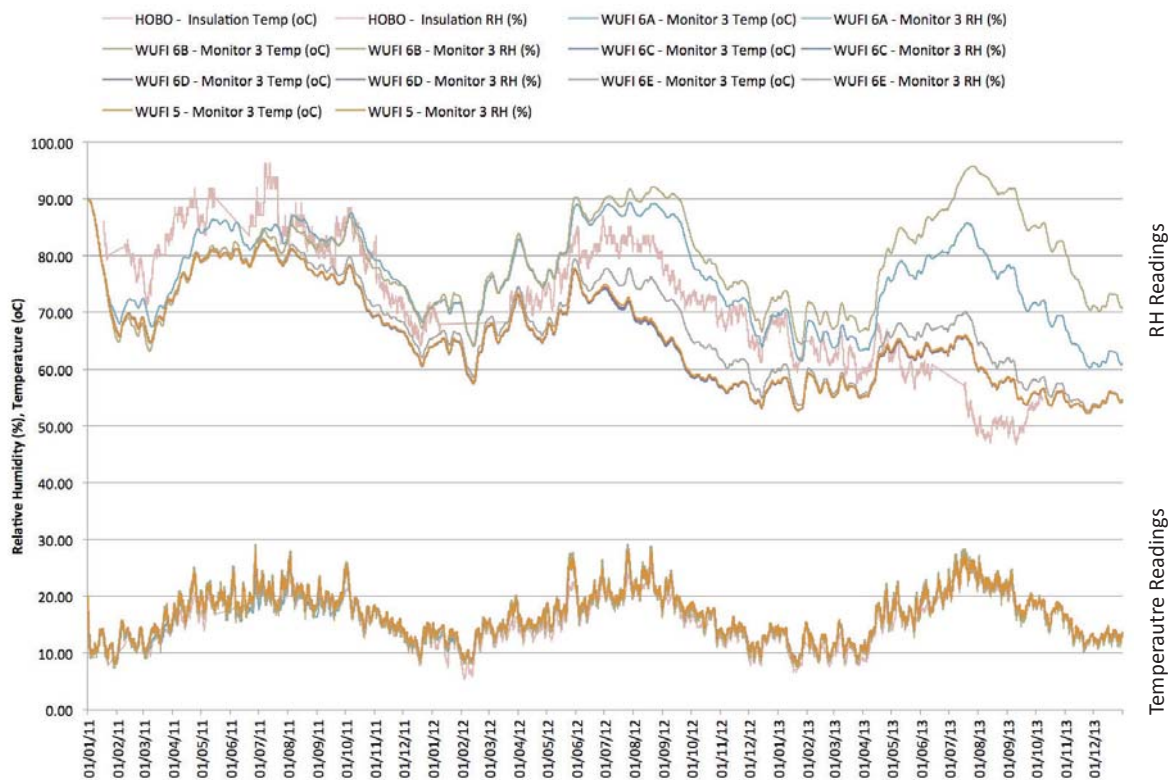


Figure 5: WUFI 5 and 6a-6f results compared with Insulation HOBO measurements – Temperature and RH courses within front wall insulation



Changes were made to the mortar and old plaster. Introducing a very high diffusion resistance factor resulted in much higher RH levels at the brick/old plaster interface than reality. Removing the old plaster altogether resulted in reasonable alignment with the Brick HOBOT but much lower RH levels than the Insulation HOBOT. Whilst the impacts were not extreme, knowing these materials' properties is still clearly important (Khayatt, 2016).

Little and Arregi (2013) have shown that the insulation type and breathability is hugely significant. However this research looked solely at sheep's wool insulation and only tested one parameter – the lambda value – which appeared to have little impact. No real conclusions can be drawn regarding the insulation.

Table 2 summarises the parameters, which this exercise has revealed make a significant impact on the WUFI Pro results. Practical recommendations are also made.

Table 2: Summary of input parameters, which are significant in WUFI Pro

Parameter	Observed Impact	Recommendations
Diffuse & Direct Radiation OR Diffuse & Global Radi'n OR Incidental & Global Radi'n (optional)	Significant	Must include radiation data. For research comparing measured data with WUFI modelling, measure incidental radiation on wall in question over time. Alternatively, estimate diffuse radiation from global radiation data, which is easily obtainable. Further research required on this tactic
Initial conditions (required)	Significant over first 1-2yrs	Measure moisture levels over time within un-refurbished wall to act as a guide for the brick and plaster. Obtain typical built-in moisture information from manufacturers for the new materials.
Surface short-wave radiation absorptivity (optional)	Significant	-
Brick – basic (required) and hygric (optional) properties	Significant – especially the A-value	Measure several samples of brick from the wall in question. Refer to Browne (2012).
Mortar – basic (required) and hygric (optional) properties	Minor	-
Old internal plaster – basic (required) and hygric (optional) properties	Significant	Measure several samples of plaster from the wall in question. Refer to Browne (2012).
Insulation – basic (required) and hygric (optional) properties	Inconclusive as looked only at sheep's wool	-

Interestingly, the wall seems to perform worse in WUFI than in reality – a finding, which echoes Baker and Phillipson's Glaswegian research (2015). The brick/insulation interface is drier in reality than in all of the WUFI models. Whilst the insulation starts off wetter in reality, by 2013 it has dried out more than WUFI predicts. This could be because the WUFI model assumes full bonds between all the wall's materials when in reality there will be small gaps within the bricks and mortar. This 'full-bond' assumption produces worst-case scenarios for both high U-Values and moisture contents (O'Leary et al, 2015).

## Conclusion

WUFI Pro is an incredibly powerful tool that can provide comprehensive information on moisture levels and movement within a wall and thus greatly inform moisture risk analysis.

A better understanding of potential mould growth can be achieved by using the add-on WUFI Bio. However, in traditional solid wall properties, WUFI Pro must be used in conjunction with WUFI 2D so that moisture levels within timber joist ends and at critical junctions can be examined.

The reliability of WUFI Pro's results depends entirely on the accuracy of the data inputted into the model. This is especially true when WUFI Pro is used as a prediction tool with no measured data against which the model can be compared and adjusted. It is tempting to only input the most basic information required by WUFI Pro as both climate and material data can be hard to obtain. However such an approach could lead to unacceptably inaccurate results and give the user a false confidence – especially as WUFI's outputs are so comprehensive. It is also tempting to input material properties, which lead to worst-case scenarios in order to 'play it safe'. However, such an approach could lead to falsely conservative results and condemn an IWI strategy, which may actually work. It is essential therefore that the data inputted into the model is both comprehensive and precise. These findings concur with other research (Little, 2011; Browne, 2012; May and Rye, 2012).

### ***Recommendations for Further Research***

Due to the limited number of UK case studies like this, it is useful to examine where improvements to the methodology could have been made to aid future, similar research.

Firstly, measured data should be collected for a minimum of three to four years so that year on year equilibrium is likely to be achieved and can be observed. RH levels and temperature should be monitored at multiple depths within the wall. HOBOs are simple, low-cost monitors, but they must be checked regularly to minimise data loss and multiple monitors are needed at each wall depth to iron out anomalies and accuracy loss. RH levels and temperature near joist ends and moisture content within joist ends should also be measured. Extended electrical resistance pins can be inserted into joist ends to measure moisture content directly (Ueno, 2015).

Secondly, the external climate on the wall itself needs to be measured including: RH, temperature, vertical rain, wind speed, wind direction and global/diffuse/incident solar radiation. Alternatively local weather station data can be obtained from the UK Met Office through their BADC/CEDA website but incident and diffuse radiation are rarely monitored. The author estimated diffuse radiation from global radiation but further research is required to establish if the tactic employed here is sufficiently precise for WUFI's purposes.

Thirdly, the wall's materials – in particular the brick and old internal plaster – must be tested to obtain precise properties. Browne (2012) proposes simple testing procedures. In general, wide scale and comprehensive testing of UK traditional building materials is required and a central database should be created.

### **References**

- Baker, P., Phillipson, M., 2015. Pre-1919 Energy Efficiency Pilot Study. Elder Street, Govan. Monitoring, Analysis & Modelling. In *Historic Scotland, Hygrothermal assessment and simulation in building conservation and retrofit*. Edinburgh, 24th February 2015. Glasgow: Baker & Phillipson.
- Bradshaw, F. 2017. *Hawthorn Road Discussion*. (Personal meeting with the project architect, 22.06.17.)
- British Standards Institution (BSI), 2012. BS EN ISO 13788: 2012. *Hygrothermal performance of building components and building elements — Internal surface temperature to avoid critical surface humidity and interstitial condensation — Calculation methods*. Milton Keynes: BSI.
- Browne, D., 2012. *The SPAB research report 3. The SPAB Hygrothermal Modelling survey. Interim report. October 2012* (pdf report) London: Society for Protection of Ancient Buildings (SPAB).

- Croxford, B., 2013. *Hawthorn Road PassivTerrace: Final Monitoring Report for TSB, March 2013* [pdf report]. London: University College London.
- Croxford, B., 2015. *CAT Hawthorn Road*. [skype call] (Personal Communication, 30.10.15).
- Onset, n.d.a.. *Testing the Accuracy of Sensirion Relative Humidity Sensors in HOBO® Data Loggers*.
- Department for Energy and Climate Change (DECC), 2015. *UK progress towards GHG emissions reduction targets. Statistical release: Official Statistics*. 19th March 2015. London: DECC.
- Fraunhofer IBP, n.d.. *WUFI Add-Ons*. (webpage).
- Fraunhofer IBP, 2015a. *WUFI Home*. (webpage).
- Joint Research Council, (JRC), 2015. *Photovoltaic Geographical Information System - Interactive Maps*. [webpage].
- Khayatt, A. (2016). *Can Masonry Solid Wall Dwellings be Insulated with Internal Wall Insulation to High Energy-Efficiency Standards Without Introducing Moisture Risks? A Case Study Analysis*. MSc. Centre for Alternative Technology, University of East London.
- Künzel, H.M., 1995. *Simultaneous Heat and Moisture Transfer in Building Components*. Holzkirchen: Fraunhofer Institute.
- Künzel, H.M., 1998a. Effect of interior and exterior insulation on the hygrothermal behaviour of exposed walls. *Materials and Structures/Materiaux et Constructions*, Vol. 31, pp99-103.
- Kunzel, H.M., 1998b. *More moisture load tolerance of construction assemblies through the application of a smart vapour retarder*. Holzkirchen: Fraunhofer Institute.
- Little, J., 2010a. Breaking the Mould 4. In *Construct Ireland*. 11(4).
- Little, J., 2010b. Breaking the Mould 5. In *Construct Ireland*, 12(4).
- Little, J., 2011. *Insulation retrofit of traditional buildings Do we know what we are doing? Introducing hygrothermal building physics and WUFI simulations*. [pdf presentation].
- Little, J., Arregi, B., 2013. Managing moisture – the key to healthy internal wall insulation retrofits of solid walls. In *Passivhaus, 17th International Passive House Conference*. Frankfurt am Main, 20 April 2013. Dublin: Little.
- Little, J., Arregi, B., 2016. Hygrothermal Risk Evaluation for the Retrofit of a Typical Solid-walled Dwelling, *SDAR Journal of Sustainable Design & Applied Research*, Vol. 4, Issue 1, Article 3.
- May, N., 2005. *Breathability, the key to building performance*. [pdf essay].
- May, N., Rye, C., 2012. *Responsible Retrofit of Traditional Buildings*. [pdf report]. London: Sustainable Traditional Buildings Alliance (STBA).
- Marincioni, V., 2015. Hygrothermal behaviour of internally insulated walls. In *Historic Scotland, Hygrothermal assessment and simulation in building conservation and retrofit*. Edinburgh, 24<sup>th</sup> February 2015. London: Marincioni.
- O'Leary, T., Menzies, G., Duffy, A., 2015. The Design of a Modelling, Monitoring and Validation Method for a Solid Wall Structure. *Energy Procedia*, Vol. 78, pp243–248.
- Sanders, C., 2015. Development of moisture assessments for construction design Dewpoint to WUFI and beyond. In *Historic Scotland, Hygrothermal assessment and simulation in building conservation and retrofit*. Edinburgh, 24<sup>th</sup> February 2015. Glasgow: Glasgow Caledonian University.
- Second Nature UK Ltd, n.d.. *Fact Sheet: Thermafleece PB20*. [Manufacturer's product data sheet]. Penrith: Second Nature UK Ltd.
- Sedlbauer, K., 2001. *Prediction of mould fungus formation on the surface of and inside building components*. Holzkirchen: Fraunhofer Institut
- Sedlbauer, K., Kunzel, H.M., 2006. *Frost Damage of Masonry Walls – A hygrothermal Analysis by Computer Simulations*. Holzkirchen: Fraunhofer Institut.
- Smith, M. 2017. Avoidance and Diagnosis of Problems Associated with Internal Wall Insulation. *Journal of Building Survey, Appraisal & Valuation*, Vol. 6, No.1, pp11-25.
- Straube, J., Schumacher, C., 2006. Assessing the durability impacts of energy efficient enclosure upgrades using hygrothermal modeling. *WTA Journal*, 2.
- Straube, J., 2009. Measuring the impact of internal insulation on solid masonry walls in a cold climate: Conference paper 0910. *Building Science.com*.
- Straube, J., Schumacher, C., Mensinga, P., 2010. Assessing the Freeze- Thaw Resistance of Clay Brick for Interior Insulation Retrofit Projects. *Building Science Press*, Conference Paper – 1013.
- Ueno, K., 2015. Analysis of Joist Masonry Moisture Content Monitoring. *Building America Report* – 1508.
- WUFI Administrator, 2009. *Frost damage conditions and internal insulation*. (WUFI online forum).

# Performance-driven Façade Design Using an Evolutionary Multi-Objective Optimization Approach

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**Abstract:** The complexity of design problems implies facing several variables at the same time to reach different criteria which could be contradictory. Thus, different objectives should be considered simultaneously which could be handled using Multi-objective optimization approach. This paper focuses on the performance of building façade regarding daylighting and energy loads. Being the main element that separate between the outside conditions and the indoor built environment, it is important to consider its performance from the early design stage. It is aimed to determine the applicability of *Genetic Algorithm* (GA) to optimize the design of a parametric double skin façade to maintain sufficient daylighting conditions to meet LEED V4 requirements while maximizing energy savings. As a case study, the design of the external façade of a generic reading space was used. The evolutionary principles of GA were utilized to optimize this façade through the Octopus tool in *Grasshopper* (GH). GH is a parametric platform securely integrated with Rhinoceros 3D modelling software by which the parametric façade was modelled. Also, *Diva-for-Rhino* was used which interfaces *Radiance* and *Energy plus* engines for daylighting and energy loads calculations. Daylight illuminance and annual energy loads of cooling and heating were used as objective functions. The results showed the robustness of the GA in the Multi-objective optimization process to effectively evolve the design of the façade pattern considering the assigned criteria. The workflow suggested in this paper have presented promising results not only by giving a trade-off between daylighting and energy savings but also by meeting innovative aspirations and subjective requirements of the designer which may inappropriately control the design practice.

**Keywords:** Performance-driven, Façade design, Multi-objective optimization, Daylighting, Energy savings

## Introduction

In the context of the current energy crisis and climatic changes, and with the increased demand on low-energy built environment; the study of building envelope has become inevitable in order to reduce the energy use. The design of the building façade has a significant effect on its energy performance. It impacts the amount of daylighting penetrating the building, as well as artificial lighting, cooling and heating energy loads. To design the façade of a building we need to take into account multiple interacting parameters of both client, designer, environmental aspects and economic aspects. The complexity of the design problem thus implies dealing with all these several aspects at the same time, trying to fulfil different criteria which themselves might be contradicting. This could be formulated as a Multi-objective optimization problem.

Optimization, also known as mathematical programming techniques, means to obtain the best result under certain circumstances, i.e., to minimize the effort or to maximize the benefit. There are two types of optimization problems according to the involved number of objective functions; single-objective and multi-objectives (Rao & Rao, 2009). Whereas optimizing objectives sequentially with problems that involve multiple contradicting objectives will possibly result in conflict; Multi-objective optimization can particularly be useful as it involves considering several objectives simultaneously and thus can offer the designer a set of equally optimal solutions that all lie within the trade-off between two or more contradicting goals.

There are typically two popular approaches to solve Multi-objective optimization problems. The first one uses a "*weighted sum function*" where the various objectives are combined to form one single objective, which is then optimized. This means that the problem has been turned into a single-objective optimization where weight factors are assigned for each criterion and the cost function will be the weighted sum of these criteria (Nguyen et al., 2014). The other approach is to use "*Pareto optimization*"; a popular approach for Multi-objective optimization. A solution is said to be Pareto-optimal if it is non-dominated, i.e.; if there is no other feasible solution that can improve one objective without deteriorating at least another one, thus this set of non-dominated solutions is called "*Pareto frontier*" (Machairas et al., 2014). Although Multi-objective optimization is more relevant than single objective optimization with building design problems in most of the cases, however, Multi-objective optimization is only applied in 40% in this field of research (Evins, 2013).

There exist many optimization methods that have been recently developed, most of which in the last few decades, and have not originated primarily in mathematics. These have rather drawn inspiration from nature (Wahde, 2008). They are considered heuristic (or meta-heuristic) methods mimicking natural strategies, and therefore; they are highly superior to exact methods in complex optimization problems. *Evolutionary Algorithms (EAs)* and *Genetic Algorithm (GA)* are particularly the most predominant class of this category. The Genetic Algorithm has been one of the most popular techniques in *Evolutionary Computation (EC)* research; a paradigm in artificial intelligence involved with the iterative progress of collective phenomena related to growth, reproduction, selection and survival in adaptive populations. Evolutionary algorithms designate a class of optimization methods that are based on the abstraction of natural evolution related to Charles Darwin's theory of natural selection, as well as the principles of genetics and natural heredity mechanisms (Binitha & Sathya, 2012). Members of the EAs family, and Genetic Algorithm on top of them, are all population-based stochastic search methods based on best-to-survive criteria.

Many researchers are interested in comparing the performance of different algorithms in solving building optimization problems as one of the criteria for selecting an optimization algorithm. GA has been one of the most popular algorithms which have proven its robustness in solving building optimization problems. Wetter and Wright (2003) compared between the performance of the *Hooke-Jeeves (HJ)* pattern search optimization algorithm and the *Simple Genetic Algorithm (SGA)* in the optimization of cost functions with large discontinuities. SGA outperformed the Hooke-Jeeves algorithm due to large discontinuities in the cost function. Wetter and Wright (2004) compared the performance of GA with other eight optimization algorithms for both smooth and discontinuous cost functions. GA consistently got close to the best minimum with low number of simulations and the *hybrid particle swarm and Hooke-Jeeves algorithm* achieved the overall biggest cost reductions but with a higher number of simulations than the simple GA. Bichiou and Krarti (2011) compared between GA, *Particle Swarm Optimization (PSO)*, and *Sequential Search (SS)*. Compared to PSO and SS, GA required typically the least computational time. Nguyen et al. (2014) in a review on simulation-based optimization methods found that the meta-heuristic search algorithms (e.g. GA, PSO) are the most popular algorithmic technique applied to building optimization problems. In earlier work (Fareed et al., 2016) made a comprehensive review of a total of 83 significant research studies applying evolutionary optimization methods to various building design problems in 17 different key fields. GA was



found to be the most dominant optimization method included in almost 90% of the works included in the summary.

Using evolutionary principles, Genetic Algorithm can thus solve complicated problems. Being a population-based optimization method, GA can keep in memory more than one single solution at each iteration. Applying the rules of natural selection, GA can converge to optimal solutions over many generations. With multiple offspring in a population which can act like independent agents, the population can simultaneously explore the search space in several directions to avoid being trapped to a local optimum. This study focuses on the performance of building façade regarding daylighting and energy loads. Being the main element that separates between the outside conditions and the indoor environment, it is important to consider its performance from the early stages of the design process. The objective of this study is to determine the applicability of Genetic Algorithm to optimize the design of a parametric double skin façade to maintain sufficient daylighting conditions to meet LEED V4 requirements and at the same time maximize the energy savings.

### Related research

Architectural design values and aesthetics make up an important part influencing the designer to make their design decisions. And although there are many previous studies on the optimization of the energy and daylighting performance of building façades, yet only few of them tried to implement these studies to an actual design which responds to the values and intentions of the designer's subjectivity. Also most of the published work, as mentioned before, applied single-criteria or weighed-sum optimization in order to save time and effort. Torres and Sakamoto (2007) used GA for façade design optimization of daylighting to maximize energy savings by maintaining good daylight penetration where fitness was defined as the proportion of the annual lighting requirements that could be replaced by daylight. Fitness function was defined as the proportion of the annual lighting requirements which could be replaced by daylight. Wright and Mourshed (2009) used GA search method to optimize the design of fenestration (the arrangement of windows in a building) where the shape, number, and position of windows were optimized to minimize energy usage. The objective function was defined as the sum of  $Q_{l}^{Heat}$ ,  $Q_{l}^{Cool}$  and  $Q_{l}^{light}$ . The façade was divided to cells that are either a "solid wall" or a "window", and a binary-encoded GA was used to optimize the state of each cell. The optimization was based on an atrium of a three-storey commercial building located in Chicago. Tuhus-Dubrow and Krarti (2010) coupled GA to a building energy simulation engine to optimize a set of parameters related to the building skin aiming to minimize energy usage for residential buildings. Shan (2014) applied GA to find the optimal façade design with respect to heating, cooling and lighting load to achieve the minimum annual energy cost. The objective function  $C_{total}$  was defined by the weighted sum of  $Q_{Heat}$ ,  $Q_{Cool}$  and  $Q_{light}$ . Radiance was used for daylight calculations, and the building performance simulation program "*TRaNsient SYstem Simulation*" (*TRNSYS*) was used to compute the energy load.

Some of the previous related research have also applied Multi-objective optimization techniques. Gagne and Andersen (2010) presented a GA-based tool to explore facade designs generated based on illuminance and/or glare objectives with parameters including materials, geometry of apertures and shading devices. This has been implemented in Google SketchUp. The proposed approach which utilizes a Micro-GA algorithm that was found valid for both single-objective problems considering illuminance only for facades facing North and South, while Multi-objective problem considering both illuminance and glare for facades



facing East and West. Evins et al. (2011) used *Non-Dominated Sorting Genetic Algorithm II (NSGAII)* to optimize the performance of a double-skin façade to discover the best configuration and control strategies. Cooling load and heating load were defined as the two objectives functions. A thermal and air-flow simulation of each proposed solution was performed using EnergyPlus. Wright et al. (2014) used NSGA-II to optimize the shape, number and position of windows of a cellular building façade to find the trade-off between the minimum building energy use associated with heating, cooling and artificial lighting, and the minimum capital cost of façade construction.

Many of these previous studies limited their scope to an abstract initial geometry with the window shapes typically being rectangular and the optimization process was only limited to the size and position of these openings. Although this may result in minimizing energy consumption, they are concerning the architectural design values and aesthetics decisions taken by the designer or client. In this study, unlike previous work, the subjective design requirements were considered to optimize the performance of the building façade regarding daylighting and energy loads. So, the design, shown in Figure 1, of an external parametric diamond grid façade of a student library previously proposed by the second author in an international competition will be used as a case study. To have more comprehensive understanding of the daylighting and energy performance, the proposed design was examined in the four main orientations with very few deviations from the original design.



Figure 1. Original design of the library

## Methodology

The study was conducted first on a generic South oriented reading space located in the desert climate of Cairo, Egypt (30°6'N, 31°24'E) with no external obstruction. Then, the three other main orientations; North, East, and West were examined. The space configuration and the parameters of the double skin façade was shown in Table 1 and Figure 2 respectively. Although it was intended to evaluate the impact of the proposed design of the double-skin façade regarding the daylighting and energy performance in this study, two base cases were considered; single façade (*identified as base case 1*), and double-skin façade (*identified as base case 2*), in order to provide more comprehensive results. According to (Fathy et al., 2015) and (Wagdy & Fathy, 2015), external screen was applied on a South oriented façade in Cairo where depth ratio 1:1 was found to be the most successful in reaching a balance between avoiding direct sunlight that causes heat gain and providing

adequate daylight . Thus, parameters of base case 2 (double façade) was fixed to distance 50 cm from the main wall and depth 20 cm to form a total extrusion length 70 cm equals to the grid size 70 cm.

Table 1. Space and window parameters

Space Dimensions	Floor Level	Ground floor (+105 cm)
	Internal Dimensions	700*800 cm
	Floor Height	600 cm
Internal Surfaces Reflectance	Ceiling	80% White colour paint
	Walls	50% off-white colour paint
	Floor	20% Wooden floor
Window Parameters	Window to Wall Ratio (WWR)	87%
	Window height	520 cm
	Window width	800 cm
	Glazing	Double Clear Pane (VT=80%)
	Window Frame	Metal Diffuse

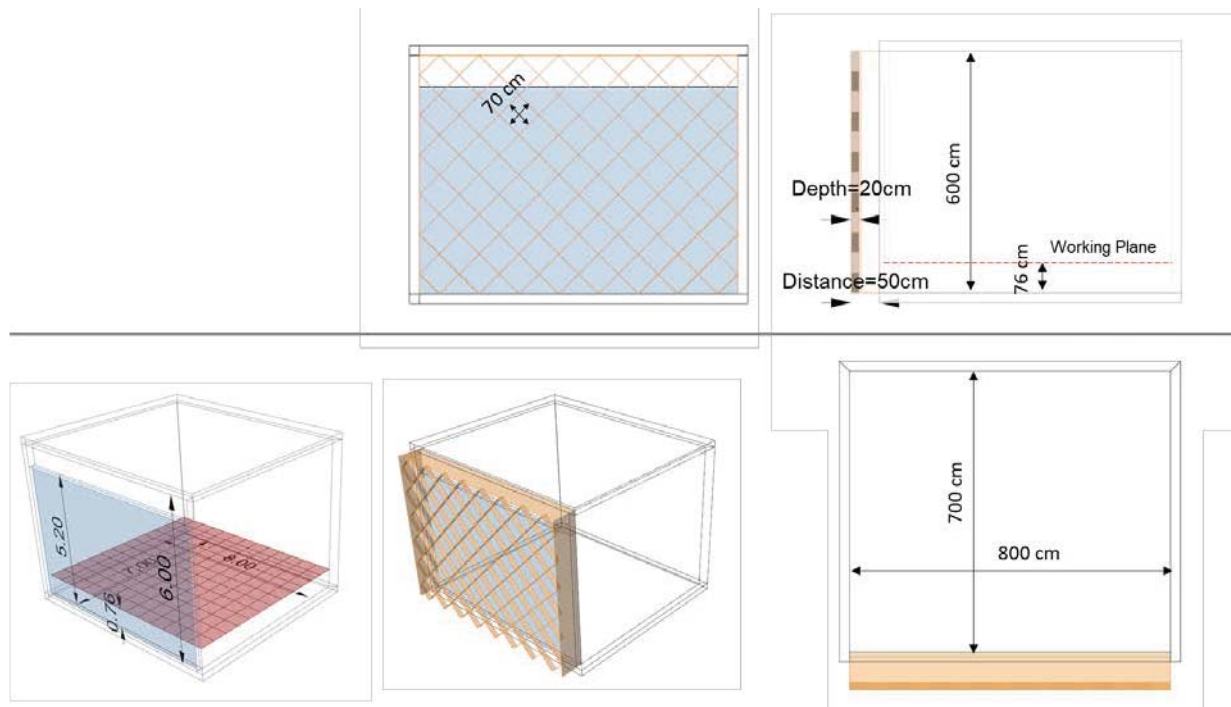


Figure 2. Space dimensions showing the 2 base cases, single and double skin façade

### Double skin Facade Modelling

A parametric square diamond grid facade 70\*70 cm with reflectance 35% is constructed in front of a glazing façade directed to the South orientation. Several parameters were identified to explore their variations on daylighting and energy performance which are: 1) *Distance* between the outer skin (Square grid) and the inner skin (Glazing) ranging from 10 to 100 cm with 5 cm increment, 2) *Depth* of the outer skin ranges between 5 to 100 cm with 5 cm increment, 3) *Openness factor* which represents the ratio of opened cells (solid and void) in the outer façade, it ranges from 0.1 to 0.9, 4) *Scale factor* of the opened cells which was related and adjusted by two attraction points to create a random parametric pattern on the façade as shown in Figure 3. The distance between the centroid of each cell and the nearer attraction point was correlated to the scale of its openness whereas the cell gets more opened as the distance increase. The scale factor was set with minimum and

maximum value of 0.1 and 0.9 respectively. These four variables were set as an input to generate the whole façade which resulted in thousands of possibilities.

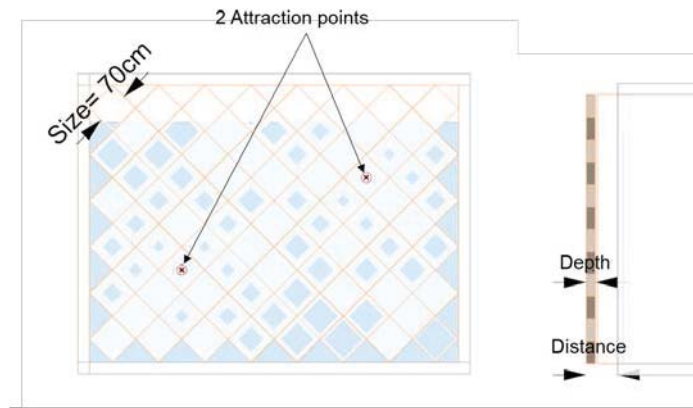


Figure 3. Elevation and Section of the double skin showing its parameters

### Optimization Process

Searching through the large number of alternatives to find the optimal solutions was approached using Multi-Objective Optimization. The assigned performance criteria were concerned with enhancing daylighting and minimizing energy loads while maintaining the visual aspects. This was tested through the adjustments of the parametric façade variables. The modelling platform used was *Rhinoceros* 3D-modelling software and its parametric plugin *Grasshopper (GH)* (Rutten, 2017). The Optimization tool used was the evolutionary solver *Octopus*. It is a plugin for GH that applies the principles of *Genetic Algorithm (GA)* to find the trade-off between two or more design objectives. In this study, three objectives were defined: 1) *Illuminance at 9am should be within the range of 300 to 3000 Lux*, 2) *the same illuminance range should be attained at 3pm while* 3) *minimizing energy loads*. To find the trade-off between the three objectives which are usually contradicting, a Pareto frontier was produced to find non-dominated solutions. 10 generations were simulated with a population size set to 5 solutions. This process was done sequentially on the four orientations: South, North, East, and West.

### Simulation Parameters

Simulations were conducted on 21<sup>st</sup> of September and 21<sup>st</sup> of March then, the average illuminance values for both days were used. Illuminance levels were calculated on the working plane divided into a grid of 50\*60 cm grid forming 156 sensor points at 76 cm above the ground. According to *LEED V4* requirements (USGBC, 2017), the floor area that meets the criteria should be more than 75% to achieve 1 point and more than 90% for 2 points. The targeted percentage for this case study was of minimum 75%. *Diva-for Rhino* is a simulation tool that was used for daylighting illuminance and energy loads calculations. It interfaces the simulation engines *Radiance* and *Daysim* for daylighting and *Energy Plus* for energy calculations. Radiance parameters were set with 6 ambient bounces, 1000 ambient divisions and 0 direct threshold.

Energy loads for heating and cooling were computed using also *Diva Viper* component in Grasshopper. It was intended to evaluate the effect of the double façade design on the energy performance so, other parameters were neutralized. All space surfaces were set to be adiabatic except the window wall with glazing U-value 0.75 W/m<sup>2</sup>/K, and solar heat gain coefficient (SHGC) 0.25. The occupancy of the space was set at a rate of 0.1 Persons/m<sup>2</sup> and

the time schedule from 8am to 6pm was assigned. Heating and cooling set points were set 22 °C and 26 °C respectively.

## Simulation Results

Results were analysed for the South orientation then, compared to the three other orientations in terms of the two base cases and the optimal solution selected.

### South Oriented Façade

First, the space was evaluated with a single façade design which was identified as base case (1). It was found that it did not meet both criteria of daylighting, as the percentage of space reaching the required illuminance range was only 57.05% and 60.9% at 9am and 3pm respectively. As shown in Figure 4, the problem lies in the over lit area, which exceeds 3000 Lux, as it was dominating the space area. Whereas, in base case (2) the employed double skin façade enhanced the illuminance levels to be within the specified range and was achieved in more than 75% of the space area as shown in Figure 4. Moreover, a dramatic decrease in total energy loads (cooling and heating) was noticed in the double skin façade with difference of 106.3 KWh/m<sup>2</sup> between base case (1) and (2) as shown in Figure 5.

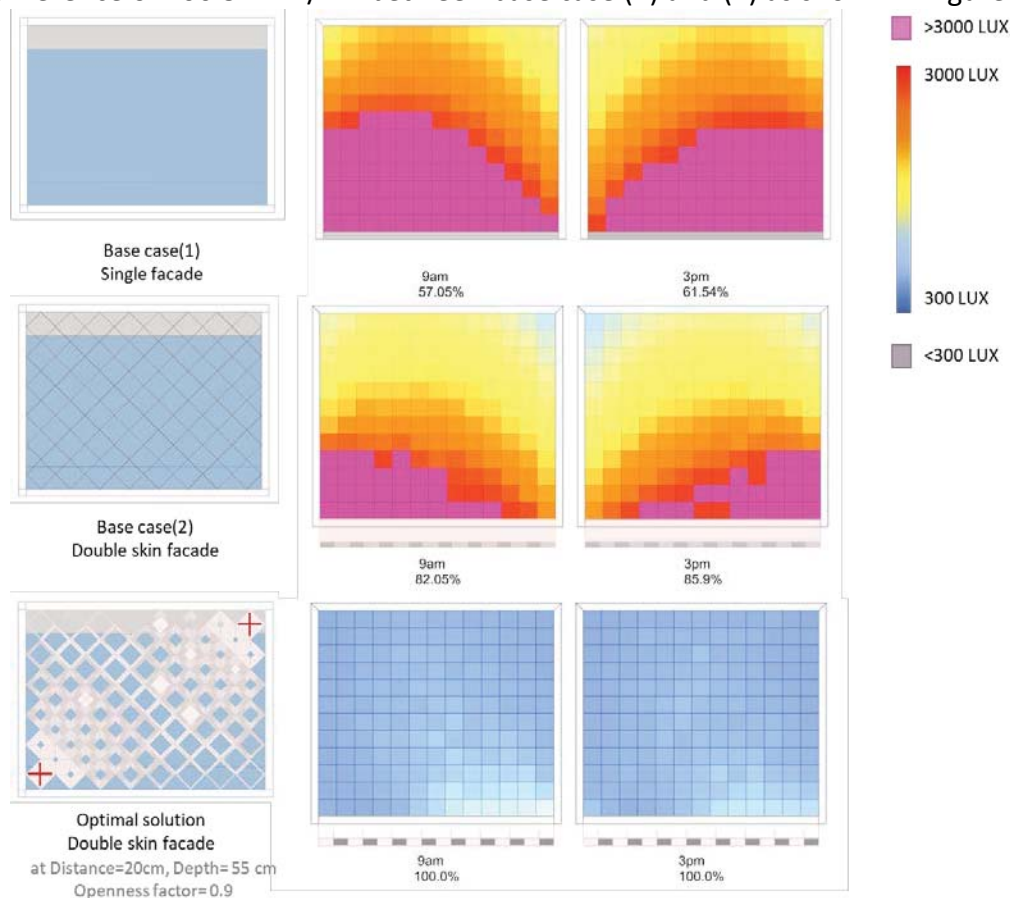


Figure 4: Daylight Distribution for the two base cases and an optimal solution showing their corresponding façade elevation

Then, the optimization process resulted in a range of successful solutions that better enhance the performance of double skin façade regarding energy loads while keeping hourly illuminance levels within the accepted range for LEED v4. One solution was selected from the Pareto front of Octopus tool shown in Figure 6 of distance 20 cm, depth 55 cm, openness 0.9, and position of attraction points as shown in Figure 4. The space area within

the accepted range reached 100% for 9am and 3pm while decreasing the energy loads by 68.4 KWh/m<sup>2</sup> compared to base case (2). It was noted that differences in heating loads can be neglected as the major differences were caused by cooling loads as shown in Figure 5.

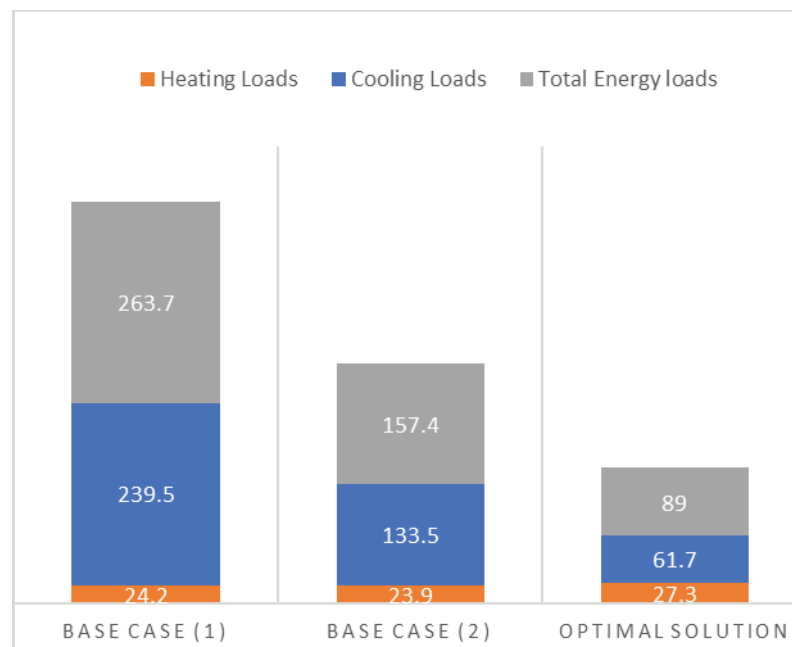


Figure 5. Energy loads in (KWh/m<sup>2</sup>) of the two base cases and an optimal solution comparing their results

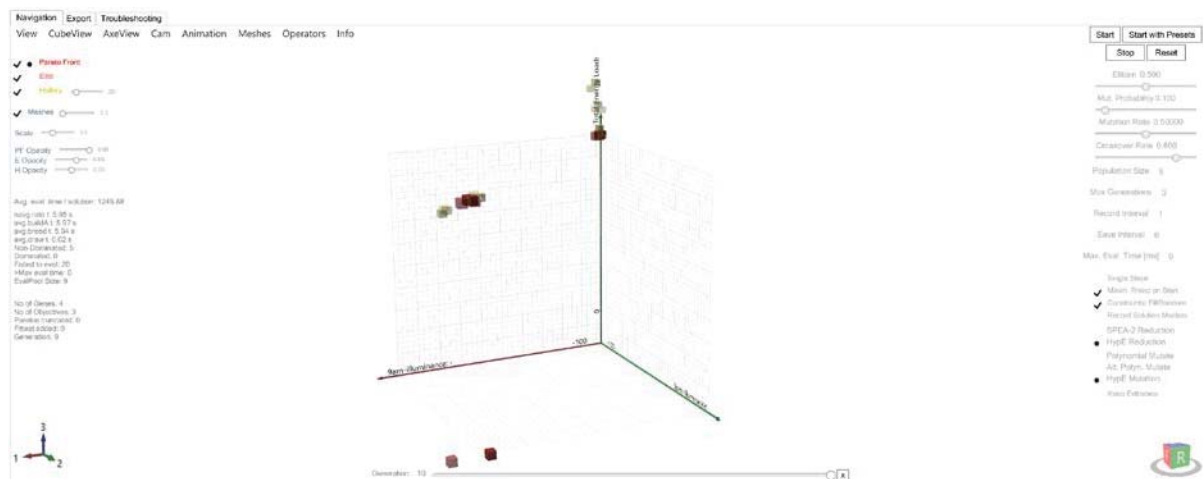


Figure 6. Octopus interface showing Pareto Front at generation 10

### North Oriented Facade

In North orientation, daylighting was successful for both single and double skin façade as no direct sunlight was entering the space. 100% of the space area reached the required illuminance levels for both cases at 9am and 3pm. However, total energy loads in the latter decreased by 33 KWh/m<sup>2</sup> to reach 115.4 KWh/m<sup>2</sup>. After the optimization process, cases with small depth and small distance lengths was found to meet the daylight criteria and energy loads were minimized. For example, at distance 10cm, depth 5cm, openness factor 0.9 and scale factor controlled by the position of attraction points as shown in Figure 7, energy loads decreased to 99 KWh/m<sup>2</sup> while maintaining daylighting criteria.



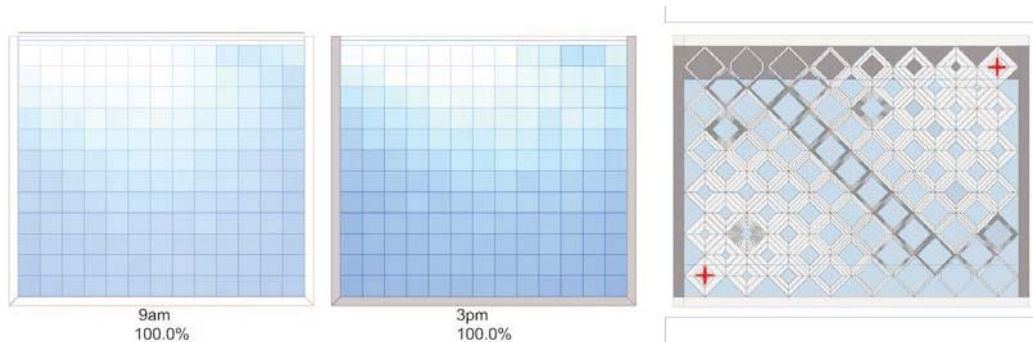


Figure 7. Optimal north double façade at distance=10 cm, depth= 5 cm, and openness factor= 0.9 showing the position of the attraction points

### East and West Orientations

In East and West orientation, unlike South and North, hourly illuminance levels at 9am and 3pm was found to be contradicting as shown in the distribution of illuminance on the working plane in Figure 8. This has complicated the search for the optimal solution for both orientations, where no solution was found to meet the criteria at 9am and 3pm simultaneously. In the East, this returns to the fact that the low sun angle results in direct sunlight penetration at 9am. On the other hand, at 3pm illuminance levels succeeded to be within the range but near the minimum benchmark (300Lux). So, any treatments applied to decrease illuminance at 9am, affected negatively on illuminance at 3pm. In the West, the same problem was encountered but with reversed hours.

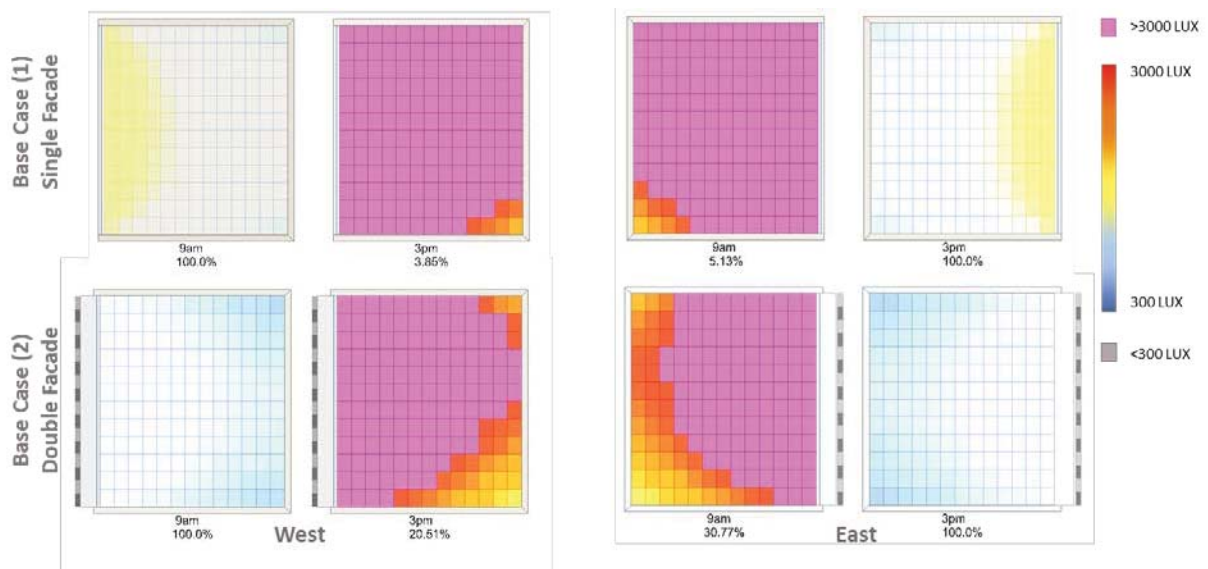


Figure 8. Hourly illuminance for the base cases at the East and West orientations

In both orientations, a slight improvement in illuminance levels was noted in double façade compared to single façade. In the East oriented façade, floor area meeting the range increased from 5.13% to 30.77% while maintaining 100% at 3pm. In the West, floor area increased from 3.85% to 20.51% at 3pm while keeping 100% of the space within the range at 9am. Besides, energy loads were decreased by about 70 KWh/m<sup>2</sup> to reach 152 and 166 KWh/m<sup>2</sup> at East and West orientation respectively as shown in Figure 9.



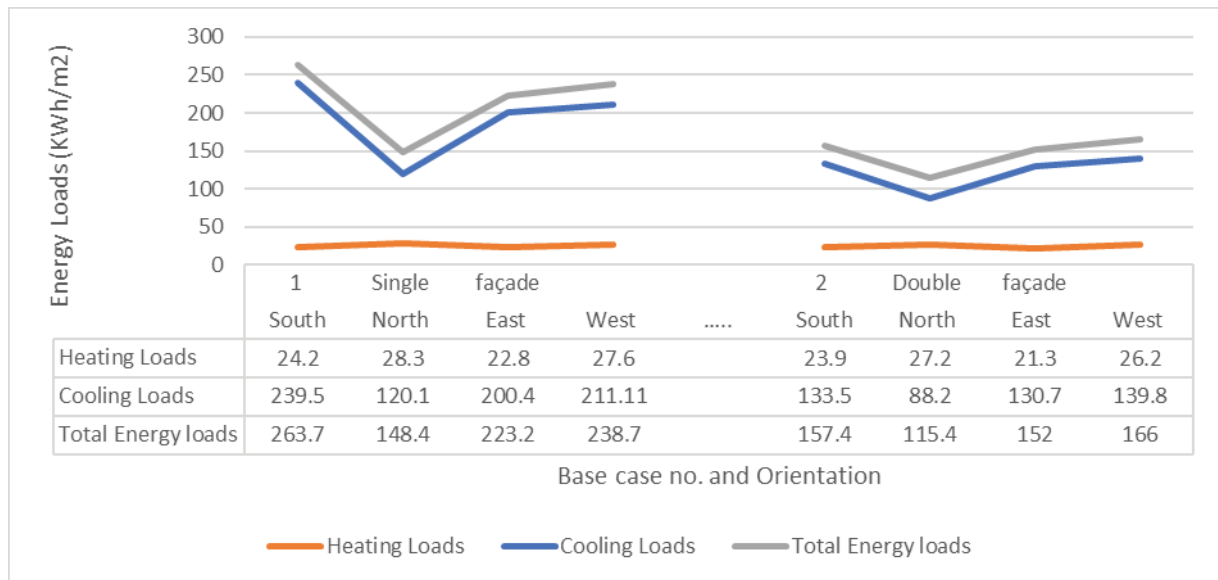


Figure 9. Energy loads for the base cases in the four orientations

Along the 10 generations of the optimization process, no solution was found to meet the daylighting criteria; however, compromised solutions can be selected. For example, in the East orientation an improvement of hourly illuminance levels at 9am was noticed to reach 86.54% of the floor area meeting the criteria at distance 35 cm, depth 5cm, openness factor 0.8, and scale factor calculated by the position of attraction points shown in Figure 10. In addition, energy loads declined to reach 103 KWh/m<sup>2</sup>. However, at 3pm illuminance levels dropped below 300Lux and floor area decreased from 100% to 35.26%.

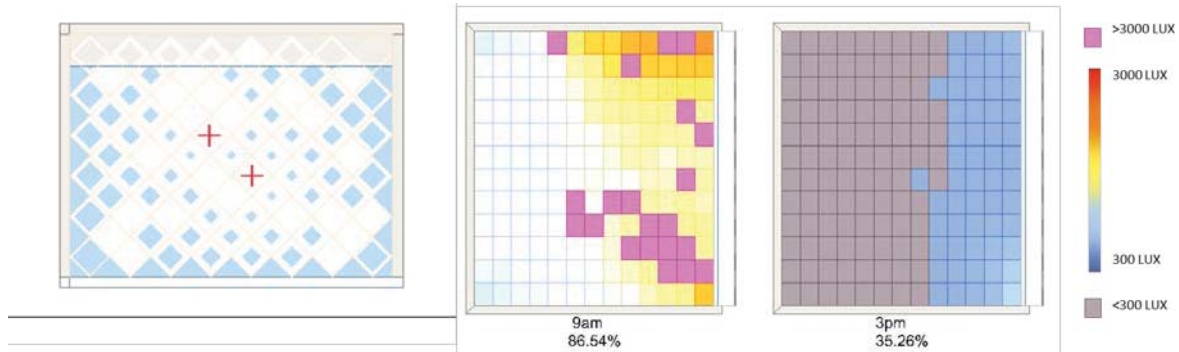


Figure 10. A compromised solution for the East orientation

## Discussion and Conclusion

This study approached façade design from an environmental perspective by using evolutionary Multi-objective optimization. Genetic Algorithm (GA) were tested in various studies and proved their robustness in building optimization problems. In this study, GA was utilized through Octopus tool which is a Multi-objective evolutionary solver to find the trade- off between daylighting and energy performance which are contradicting criteria in the hot arid climate of Cairo. Illuminance intensity at 9am and 3pm intended to be maximized to reach LEED v4 requirements while minimizing energy loads from cooling and heating. This approach resulted in a range of solutions rather than one single solution which provides the designer the flexibility and freedom to select and explore unexpected alternatives that achieve the same performance.

The optimization process was conducted for the four main orientations to explore and quantify the improvement that could be applied to the proposed façade design regarding daylighting and energy performance whereas, constrained parameters and variables ranges were defined to maintain innovative aspirations and subjective designer's requirements. A population of only 5 individuals was set and 10 generations were simulated to facilitate the process and explore GA robustness in such small population. The results indicate that GA was able to reach near optimum solutions to meet the assigned criteria for the South and North orientations, and compromised or good enough solutions for East and West orientations.

By comparing the energy loads of the four orientations in Figure 9, the North had the least energy consumption with a remarkable difference especially in base case (1). As no direct sunlight was hitting the North façade, it was the preferable orientation for both daylight and energy criteria. However, optimizing the double skin façade in other orientations offered a range of possibilities that can compete the performance of a North oriented space. For example, the optimal solution in South recorded 89KWh/m<sup>2</sup> to be 10 KWh/m<sup>2</sup> less than the optimal solution in the North. The effectiveness of double skin façade in reducing energy loads was obvious by comparing the two base cases along the four orientations. Results indicated that the magnitude of the energy savings was dominated by the cooling energy loads due to the climatic conditions of Cairo.

It could be concluded that optimization of the proposed cellular façade design not only was effective regarding daylighting and energy performance, but could reach innovative design alternatives that respond to the intentions of the designer's subjectivity as well. The same workflow can be applied on various design parameters forming a range of innovative façade designs.

### ***Limitations and Future Research***

Further optimization for the East and West orientations was still required with increasing the population size and number of generations to enhance the solution space. The integration of lighting loads would affect the energy savings; however, they were disregarded as they needed the calculation of the annual daylight performance which would result in expensive computing time and effort. Instead, daylighting simulation was evaluated using point-in-time method to meet LEED v4 requirements so, selected optimal solutions should be further analysed annually using Dynamic Daylight Performance Metrics (DDPM). The proposed optimization workflow added the dimension of environmental performance aspects to inform design decisions. Not only it can be used in early design phases for exploring successful design solutions, but in the design development as well without compromising the designers' or clients' decisions.

### **Acknowledgment**

The proposed double skin façade was initially designed by the second author in collaboration with AFH Consultant, Art-line Group & and Abdallah AlSaif & Partners in the international competition to design the student library for girl campus in King Faisal University, Al-Hasa, KSA. Image in Figure 1 was taken of the competition entry. All rights reserved.

### **References**

- Bichiou, Y., & Krarti, M. (2011). Optimization of envelope and HVAC systems selection for residential buildings. *Energy and Buildings*, 43(12), 3373-3382. doi: <http://dx.doi.org/10.1016/j.enbuild.2011.08.031>
- Binitha, S., & Sathya, S. S. (2012). A survey of bio inspired optimization algorithms. *International Journal of Soft Computing and Engineering*, 2(2), 137-151.
- Evins, R. (2013). A review of computational optimisation methods applied to sustainable building design. *Renewable and Sustainable Energy Reviews*, 22, 230-245.
- Evins, R., Pointer, P., & Vaidyanathan, R. (2011). *Multi-objective optimisation of the configuration and control of a double-skin facade*. Paper presented at the Proceedings of the building simulation.
- Fareed, H. A., Hosny, S. S., Dewidar, K., & Morcos, R. (2016). A Review on the Application of Evolutionary Algorithms to Building Design Optimization. *Engineering Research Journal - Faculty of Engineering (Shoubra)*, 27, 109-132.
- Fathy, F., Mansour, Y., Sabry, H., Abdelmohsen, S., & Wagdy, A. (2015). Cellular Automata for Efficient Daylighting Performance: Optimized Façade Treatment.
- Gagne, J., & Andersen, M. (2010, 11-13 August ). *Multi-Objective Facade Optimization for Daylighting Design Using a Genetic Algorithm*. Paper presented at the Proceedings of the 4th National Conference of IBPSA-USA SimBuild, New York, USA.
- Machairas, V., Tsangrassoulis, A., & Axarli, K. (2014). Algorithms for optimization of building design: A review. *Renewable and Sustainable Energy Reviews*, 31, 101-112.
- Nguyen, A.-T., Reiter, S., & Rigo, P. (2014). A review on simulation-based optimization methods applied to building performance analysis. *Applied Energy*, 113, 1043-1058.
- Rao, S. S., & Rao, S. (2009). *Engineering optimization: theory and practice*: John Wiley & Sons.
- Rutten, D. (2017). Grasshopper-Algorithmic modeling for Rhino software version 0.9.0076. URL <http://www.grasshopper3d.com> last accessed; . Retrieved 30-5-2017
- Shan, R. (2014). Optimization for Heating, Cooling and Lighting Load in Building Façade Design. *Energy Procedia*, 57, 1716-1725. doi: <http://dx.doi.org/10.1016/j.egypro.2014.10.142>
- Torres, S., & Sakamoto, Y. (2007). *Facade design optimisation for daylight with a simple genetic algorithm*. Paper presented at the Proceedings of Building Simulation.
- Tuhus-Dubrow, D., & Krarti, M. (2010). Genetic-algorithm based approach to optimize building envelope design for residential buildings. *Building and Environment*, 45(7), 1574-1581.
- USGBC. (2017). LEED v4, Daylight. Retrieved 1-10-2017, from <https://www.usgbc.org/node/2614118?return=/credits/new-construction/v4/indoor-environmental-quality>
- Wagdy, A., & Fathy, F. (2015). A parametric approach for achieving optimum daylighting performance through solar screens in desert climates. *Journal of Building Engineering*, 3, 155-170.
- Wahde, M. (2008). *Biologically inspired optimization methods: an introduction*: WIT press.
- Wetter, M., & Wright, J. (2003). *Comparison of a generalized pattern search and a genetic algorithm optimization method*. Paper presented at the Proceedings of the 8th International IBPSA Conference, Eindhoven, Netherlands.
- Wetter, M., & Wright, J. (2004). A comparison of deterministic and probabilistic optimization algorithms for nonsmooth simulation-based optimization. *Building and Environment*, 39(8), 989-999. doi: <http://dx.doi.org/10.1016/j.buildenv.2004.01.022>
- Wright, J. A., Brownlee, A., Mourshed, M. M., & Wang, M. (2014). Multi-objective optimization of cellular fenestration by an evolutionary algorithm. *Journal of Building Performance Simulation*, 7(1), 33-51.
- Wright, J. A., & Mourshed, M. (2009). *Geometric optimization of fenestration*. Paper presented at the Proceedings of the Eleventh International IBPSA Conference, (Building Simulation 2009), Glasgow, Scotland.

# Predicting current and future performance of sustainable lightweight buildings

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**Abstract:** This paper investigates the current and future performance of sustainable lightweight buildings in three regional climates in the UK. The study explores dynamic building simulation as a technique to understand the performance of two sustainable lightweight buildings (HWL - southeast facing and HHA - northwest facing) in the summertime (May 1-August 31) using the Test Reference Year (TRY) weather files. The weather files for the current (the 2000s) and future (the 2030s) weather scenarios of Luton in the Southeast (the warmest region), Leicester in the Midlands, and Manchester in the Northwest regions of England are considered for the study. The simulation results are validated using the data obtained during the field investigation conducted at the case study buildings in the Southeast region of England. The findings showed the average temperatures (predicted) range from 20.3°C to 20.8°C for the current weather scenario; while the predicted mean temperatures for the 2030s range from 23.1°C to 23.6°C. Higher external and internal temperatures are predicted at the case study buildings in the Southeast regional climate set-up than the Midlands and the Northwest regional climates set-up. The average summertime temperature is predicted to be lower by 0.1°C each when the window-to-wall ratio (WWR) is increased from 45% to 55% and the window height (WH) from 1.35m to 1.50m respectively. In the warmest region (Southeast), the predicted internal temperatures exceeded 25°C for 6.2% and 28°C for 0.5% of the simulated period (May-August) in the current weather scenario. While the predicted internal temperatures exceeded 25°C for over 32.5%, above 28°C for 11.4%, and even exceeded 30°C for 3.5% of the total simulated period (2952 hours) in the warmest building (HWL). In terms of the number of hours that exceeded the critical thresholds for occupants' comfort (25°C and 28°C), there is no significant change in the thermal environment of the buildings when the window-to-wall ratio (WWR) is increased from 45% to 55% and when the window height (WH) is changed from 1.35m to 1.50m. However, a noticeable change in the thermal environment is predicted when the floor area (FA) is increased by 20% and the floor-to-ceiling height (FCH) by 15%. The study showed sustainable lightweight buildings are prone to high temperatures under current and future weather scenarios even when the buildings are located in regions with cooler summertime and milder wintertime. The study also identified that the future performance of sustainable lightweight buildings can be improved using various design interventions (such as an increase in the floor area and higher floor-to-ceiling height). Finally, the study highlighted that sustainable lightweight buildings are likely to use more energy in future for cooling than current scenario and this is a crucial issue that requires further research to understand energy-load distribution during high demand period in sustainable lightweight buildings.

**Keywords:** current and future performance, sustainable lightweight buildings, regional climates, building simulation, design interventions.

## Introduction

This study examines the current and future performance of sustainable lightweight buildings in three regional climates in the UK. Over the last few decades, many studies have investigated the performance of buildings in different locations and regions of the world [Adekunle, 2014; Kendrick and Walliman, 2007; Yin et al, 2010]. Some of these studies considered building simulation as a major technique to evaluate the performance of buildings. Building performance simulation has been explored to predict future performance of newly constructed buildings. The technique has been used in retrofitting to improve the performance of existing buildings [Kendrick and Walliman, 2007; Yin et al, 2010]. Existing studies in the field have focused on the current performance of various buildings using various weather files [Adekunle and Nikolopoulou, 2016a]. These weather files are generated based on information gathered over a few decades from weather stations

located in different cities and nations to provide a representative prediction on the performance of buildings located in the regions [Adekunle and Nikolopoulou, 2016a; Herrera et al., 2017]. For instance, the Test Reference Year (TRY) weather files have been generated in more than 14 locations in the UK to understand the performance of buildings in different regional climates in the country. Also, in Australia, the Representative Meteorological Year (RMY) weather files have been developed for 69 locations; while in the United States, the Typical Meteorological Year (TMY) weather files have been generated for over 1000 locations in the nation and other locations around the world to investigate current and future performance of buildings [Herrera et al., 2017]. The development of weather files for regional climates revealed the possibility of weather variations that may occur within regions of any country. In addition, the development of regional weather files helps to understand parameters to be considered for improving both current and future performance of buildings.

Energy consumption in buildings accounts for 30% of the total energy consumption across the world every year [IEA, 2012]. Lightweight buildings tend to consume more energy than estimated at the design stage due to various factors including high temperatures in summer period [Adekunle, 2014]. High summertime temperatures have been identified as a crucial issue in buildings especially in lightweight buildings [Adekunle and Nikolopoulou, 2016a]. Existing studies highlighted thermal mass as an important issue affecting the performance of lightweight building envelopes to regulate temperature swing [Adekunle and Nikolopoulou, 2016a] when external temperatures rise above 19°C [Adekunle and Nikolopoulou, 2014]. Past investigations have examined possible interventions such as the use of phase change materials [Kendrick and Walliman, 2007; Papadopoulos and Soebarto, 2015; Long et. al., 2017], cladding materials like high-quality bricks and wood fibre cement panels with improved thermal mass to improve the performance of lightweight buildings. Design features such as an increase in floor area (FA), window height (WH) and floor-to-ceiling height (FCH) have been suggested as possible design interventions to reduce the frequency of high summertime temperatures in lightweight buildings [Adekunle and Nikolopoulou, 2016a]. Also, the integration of passive cooling strategies has been highlighted as a possible way to mitigate the impact of high summertime temperatures in lightweight buildings [Adekunle, 2014]. However, a few studies have explored the integration of passive cooling strategies and design features to improve the performance of lightweight buildings [Kendrick and Walliman, 2007].

Other features such as integration of vegetated walls are studied to improve thermal comfort of occupants and building performance of lightweight buildings [Yoshimi and Altan, 2011]. Parameters such as an increase in window area and wall thickness with additional insulation have been indicated for improving building performance of the buildings. Existing research has examined how to remove unwanted heat in buildings constructed with lightweight materials using phase change materials in building components [Kendrick and Walliman, 2007]. However, limited studies have evaluated other design parameters such as an increase in floor area (FA) of the spaces and floor-to-ceiling height (FCH) as possible design interventions to improve the performance of lightweight buildings [Adekunle, 2014]. As a result, this study investigates the current and future performance of lightweight sustainable buildings. The study also explores the increase in floor area of the buildings and floor-to-ceiling height as possible design interventions to reduce the frequency of summertime temperatures in lightweight buildings under current and future weather scenarios.

## Methodology

Dynamic building simulation has been widely used in the field by existing studies to investigate thermal comfort of occupants and performance of buildings [Kendrick and Walliman, 2007; Adekunle and Nikolopoulou, 2016a]. The technique has also been used by some studies to understand possible design interventions or passive design strategies that can be introduced to improve the performance of buildings [Kendrick and Walliman, 2007]. The simulation was considered to investigate the current performance of buildings in lightweight buildings and heavyweight buildings [Yoshimi and Altan, 2011]. Other studies have explored building simulation to predict the performance of buildings in future using weather files for future scenarios. The simulation was considered in existing studies to capture more data which may be difficult to collect during field surveys [Adekunle and Nikolopoulou, 2016a, 2016b]. Since this study considered both current and future performance of lightweight buildings in UK regional climates, building simulation helps to capture more data for analysis.

The study explored dynamic building simulation (DesignBuilder by EnergyPlus, version 4.7.0.054) as a technique to understand the performance of two sustainable lightweight buildings (HWL - southeast facing and HHA - northwest facing) during summertime for 2952 hours (that is, from May 1-August 31). The version of the building simulation software (DesignBuilder) is appropriate for the study as it is developed in line with the UK Energy Performance Certificates (EPCs) and Building Regulations for assessing buildings in England and Wales [DesignBuilder, 2010]. The modelling of the buildings was done in accordance with the architectural drawings and specification documents provided on the projects. The parameters input for the modelling of the case study buildings are presented in table 1. For the weather files, the Test Reference Year (TRY) weather files were considered for the simulation. The weather files for the current (the 2000s) and future (the 2030s) weather scenarios of Luton in the Southeast (the warmest region), Leicester in the Midlands, and Manchester in the Northwest regions of England were chosen as representative locations for the three regional climates in the UK.

The environmental parameters (temperature and relative humidity) measured at 60-minute intervals for a few weeks during the field investigation in the summer were used for calibration and validation of the simulated data. The simulated results over the same period of the field investigation were considered for the calibration and validation of this study. The charts showed the simulated and measured were aligned for the most part of the charts. After the first phase of calibrating and validating the simulated data for the period of monitoring, the calibration and validation for a longer period (May-August) were considered. The findings from the field investigation in the summer have been fully discussed in an existing study [Adekunle and Nikolopoulou, 2016a]. The charts were checked for similarities and differences. All the charts showed a similar pattern between the simulated data and the measured data with a difference of about 2.0°C for a small segment of the charts. As highlighted in existing studies, the difference of not more than 2.0°C is an acceptable range between the simulated data and measured data for validation [Adekunle and Nikolopoulou, 2016a]. Also, more than 90% of the charts showed the simulated and measured data are aligned and followed the same pattern with about 0.1°C between the simulated and measured charts for most of the time. The predicted data were also analysed using the CIBSE thermal comfort model which focuses on 5% of hours above the 25°C and 1% of hours above the 28°C thresholds [CIBSE, 2006; CIBSE 2010]. Regression analysis was also considered to find the relationships between the various parameters examined in the study.



Table 1. The parameters input for the modelling of the case study buildings

Input parameters	Value for HWL	Value for HHA
Heating required	No heating required	No heating required
Heating setpoint/setback temperatures required	No setpoint/setback temperatures required	No setpoint/setback temperatures required
Ventilation required	Natural ventilation	Natural ventilation
Density (people/m <sup>2</sup> )	0.03	0.04
Cooling setpoint/setback temperatures	No setpoint/setback temperatures required	No setpoint/setback temperatures required
Day-time	08:00 – 22:00	08:00 – 22:00
Night-time	23:00 – 07:00	23:00 – 07:00
General lighting	2.0W/m <sup>2</sup>	2.0W/m <sup>2</sup>
Task and display lighting	0.5W/m <sup>2</sup>	0.5W/m <sup>2</sup>
Metabolic (activity)	0.9	0.9
Metabolic (clothing)	0.5clo	0.5clo
Infiltration (ac/h)	0.15	0.18
Outside air change rate (ac/h)	4.0ach	4.0ach
Equipment such as computers)	3.9W/m <sup>2</sup>	3.9W/m <sup>2</sup>
Window to wall ratio	45.2%	44.5%

### Case Study Buildings

Two prototypes of sustainable lightweight buildings are selected among ten prototypes developed at the study location in the UK. The buildings were investigated during the field study. The first case study building (HWL) and the second case study building (HHA) have a similar floor area (HWL - 76.8m<sup>2</sup>; HHA - 77.0m<sup>2</sup>), floor-to-ceiling height (2.35m) and window height (1.35m). The lightweight material (structural insulated panel) is made of timber panel, rigid insulation, and cladding (Trespan). The buildings also have the same U-values for the building components such as the roof (0.17W/m<sup>2</sup>K), walls (0.12W/m<sup>2</sup>K), and windows (1.70W/m<sup>2</sup>K). However, the buildings have different orientations, number of occupants, and duration of occupancy. The HWL is an end-terrace building while the HHA is a mid-terrace building. The case study buildings were chosen as representative buildings in the study location based on orientation, occupancy pattern, placement with respect to other nearby buildings (end-terrace, mid-terrace), and design features such as floor area (FA), window-to-wall ratio (WWR), window height (WH), and floor-to-ceiling height (FCH). The first case study building (HWL) has a southeast orientation while the second case study building (HHA) has a northwest orientation with respect to the front view of each building.

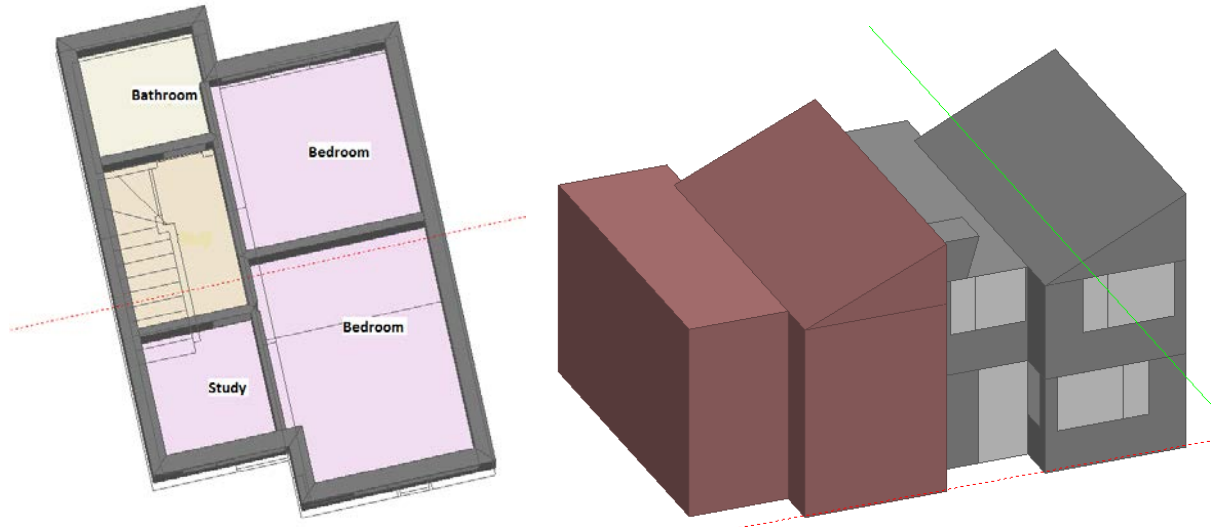


Figure 1. Modelling of HWL showing the upper floor plan (left) and 3D view (right) of the building

## Data Analysis

The analysis of the simulated external mean temperatures for the 2000s TRY showed August is predicted the warmest month in the Southeast and the Northwest. In the Midlands, July is found to be the warmest month. The external mean temperature is predicted to be above 14.0°C in July and August across the three regional climates (Figure 2). The analysis reveals higher external mean temperatures are predicted for the Southeast regional climate in July and August while higher external mean temperatures are observed in the Northwest regional climate from May to June (Table 2). The study shows the months considered for the investigation are found to be the warmest months across the regional climates.

Table 2. The predicted external mean temperatures from May-August in the regional climates

Month	Average External Temperature - TRY 2000s (°C)		
	Southeast	Midlands	Northwest
May	11.1°C	10.8°C	11.4°C
June	13.7°C	13.6°C	13.9°C
July	15.9°C	15.7°C	15.4°C
August	16.0°C	13.5°C	15.5°C

For the total period of simulation (that is, from May-August), higher external mean temperature and maximum temperature are predicted in the Southeast than the Midlands and the Northwest. On the contrary, lower external temperatures are predicted in the Southeast and the Midlands than the Northwest. Across the regions, the predicted external temperature did not rise above 5% of the 25°C and above 1% of the 28°C thresholds. Since the Southeast is found to be the warmest region, further analysis on the predicted external temperature was considered. The analysis for the 2030s TRY shows the predicted external mean temperature is found to be 17.8°C in the Southeast. The predicted temperatures rise above the 25°C indicator for 33.5% of the time while the simulated temperatures rise above the 28°C threshold for 4.3% of the time (Table 3). The analysis indicates a possibility of higher temperatures to be predicted within internal spaces of buildings located in the regions especially in the Southeast.

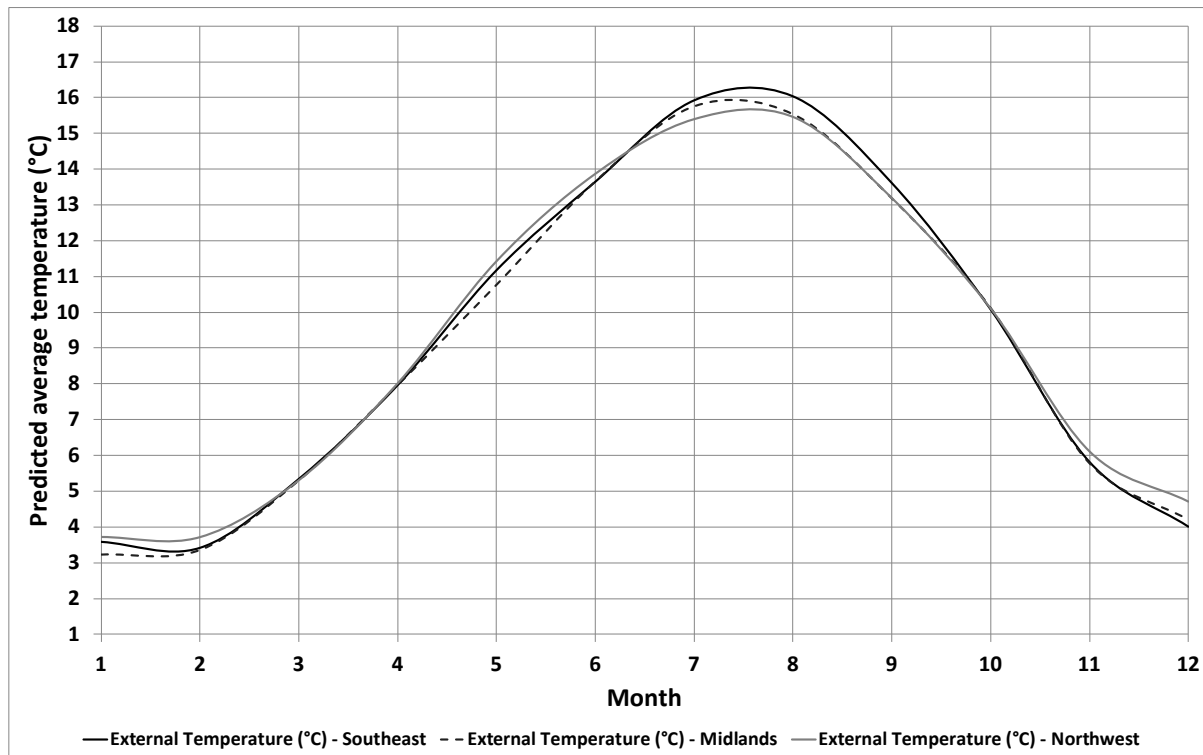


Figure 2. The predicted external mean temperatures from Jan-Dec for the 2000s TRY at the study locations

Table 3. Features of the predicted external temperature (May-August) in the regional climates

Variables	External Temperature - TRY 2000s			External Temperature - TRY 2030s
	Southeast	Midlands	Northwest	Southeast
Mean temperature	14.2°C	13.9°C	14.0°C	17.8°C
Maximum temperature	28.3°C	28.2°C	27.9°C	34.0°C
Minimum temperature	0.6°C	0.3°C	2.3°C	3.0°C
No of hours >25°C	42 (1.4%)	49 (1.7%)	21 (0.7%)	366 (38.5%)
No of hours >28°C	2 (0.03%)	1 (0.03%)	0	125 (4.3%)
No of hours >30°C	0	0	0	33 (1.1%)
No of hours >34°C	0	0	0	1 (0.03%)

## Results and Discussions

The findings show the predicted mean temperature, maximum temperature and minimum temperature for each month from May-August are higher in both buildings in the Southeast than the Midlands and the Northwest. At both buildings, the maximum temperatures are predicted to exceed the 25°C threshold in summer across the three regional climates. In the Southeast, the maximum temperatures are predicted to exceed the 28°C indicator at the HWL building in May and June. At the HHA building, the simulated temperature is also predicted to exceed the 28°C indicator in June of the 2000s TRY. In the Southeast, the external temperature is predicted to exceed the 28°C threshold in June and August. The temperature also predicted to exceed the threshold (28°C) for just one month (June) in the Midlands (Table 4).

Table 4. Current performance (monthly) of the buildings in different regional climates

Temp. (°C)	HWL (TRY 2000s)											
	Southeast				Midlands				Northwest			
	May	Jun	Jul	Aug	May	Jun	Jul	Aug	May	Jun	Jul	Aug
Mean temp	19.4	20.9	21.8	21.5	19.0	20.6	21.4	20.9	19.1	20.4	21.0	20.8
Max. temp.	28.2	30.2	27.3	27.9	25.6	27.7	27.5	26.5	25.7	26.4	27.6	25.8
Min. temp.	16.3	16.5	17.4	18.2	15.7	16.4	17.1	17.7	16.6	16.8	17.1	17.2
	HHA (TRY 2000s)											
	May	Jun	Jul	Aug	May	Jun	Jul	Aug	May	Jun	Jul	Aug
	May	Jun	Jul	Aug	May	Jun	Jul	Aug	May	Jun	Jul	Aug
Mean temp	18.9	20.4	21.3	21.3	19.1	20.5	21.2	21.0	19.2	20.3	20.9	20.7
Max. temp.	26.9	28.7	26.6	27.5	25.1	27.1	27.0	26.3	25.3	25.8	27.1	25.4
Min. temp.	16.3	16.4	17.3	17.9	16.5	17.2	17.7	18.1	16.6	17.5	17.7	17.8
	External Temperature (TRY 2000s)											
	May	Jun	Jul	Aug	May	Jun	Jul	Aug	May	Jun	Jul	Aug
	May	Jun	Jul	Aug	May	Jun	Jul	Aug	May	Jun	Jul	Aug
Mean temp	11.1	13.7	15.9	16.0	10.8	13.6	15.8	15.5	11.4	13.8	15.4	15.5
Max. temp.	26.4	28.3	26.1	28.2	25.0	28.2	27.5	26.4	25.1	25.2	27.9	24.6
Min. temp.	0.6	0.7	6.4	5.8	0.3	1.5	6.2	6.9	2.3	5.1	6.8	7.5

Note: Temperatures above 25°C are highlighted in yellow. Temperatures above 28°C are highlighted in red.

Considering the total period of the simulation (that is, May-August), higher mean, maximum and minimum temperatures are predicted at both buildings in the Southeast than the Midlands and the Northwest. The simulated temperatures also exceed the 25°C threshold for 6.1% of the time in the Southeast. The results revealed the HWL building is predicted to be warmer than the HHA building (Table 5).

Table 5. Current performance (May-Aug) of the buildings in the regional climates

Variables	HWL (TRY 2000s)			HHA (TRY 2000s)		
	Southeast	Midlands	Northwest	Southeast	Midlands	Northwest
Mean temp	20.8°C	20.5°C	20.3°C	20.5°C	20.4°C	20.3°C
Maximum temp	30.2°C	27.7°C	27.6°C	28.7°C	27.2°C	27.1°C
Minimum temp	16.3°C	15.7°C	16.0°C	16.3°C	16.5°C	16.6°C
No of hours >25°C	179 (6.1%)	91 (3.2%)	62 (2.1%)	113 (3.8%)	68 (2.3%)	46 (1.6%)
No of hours >28°C	14 (0.5%)	0	0	4 (0.1%)	0	0

Note: Temperatures above 25°C are highlighted in yellow. Temperatures above 28°C are highlighted in red.

The findings showed a strong correlation exists between the predicted internal temperature and the external temperature across the regional climates especially in the Southeast. The  $R^2$  values for the buildings under the Southeast regional climate ( $R^2$  for HWL – 0.645;  $R^2$  for HHA – 0.648) indicate there is a strong relationship between the variables (Figures 3-5). The findings of the statistical analysis presented in figures 3-5 showed an acceptable similarity of  $R^2$  values (approximately 60%-65%). However, additional statistical analysis on the simulated data will be required to further validate the findings presented in this study regarding the relationship between the variables. The predicted internal temperatures at the buildings in the Southeast have a wide range of temperature (10.4°C) than the predicted temperatures at the buildings in the Midlands (9.5°C) and the Northeast (9.2°C). The study further showed that occupants of the buildings in the Southeast are likely to adapt to a wide range of temperatures.

The study showed extreme summertime temperatures are predicted at the case study buildings. Since it appears the buildings under the Southeast climate tend to be much warmer than the buildings in the Midlands and the Northwest, further investigation was conducted to predict the current and future performance of the buildings in the Southeast

using the 2000s and 2030s TRYs. The results showed the HWL building (southeast facing) is predicted to be warmer than the HHA building (northwest facing) under both weather scenarios (Table 6). The study showed orientation, placements of the buildings with respect to other buildings (end-terrace, mid-terrace) are crucial parameters that can possibly influence the performance of lightweight buildings. The mean temperature and the maximum temperature exceed the comfort indicators (25°C and 28°C) in the 2000s and the 2030s. The results revealed extreme summertime temperatures at the case study buildings, especially in the 2030s.

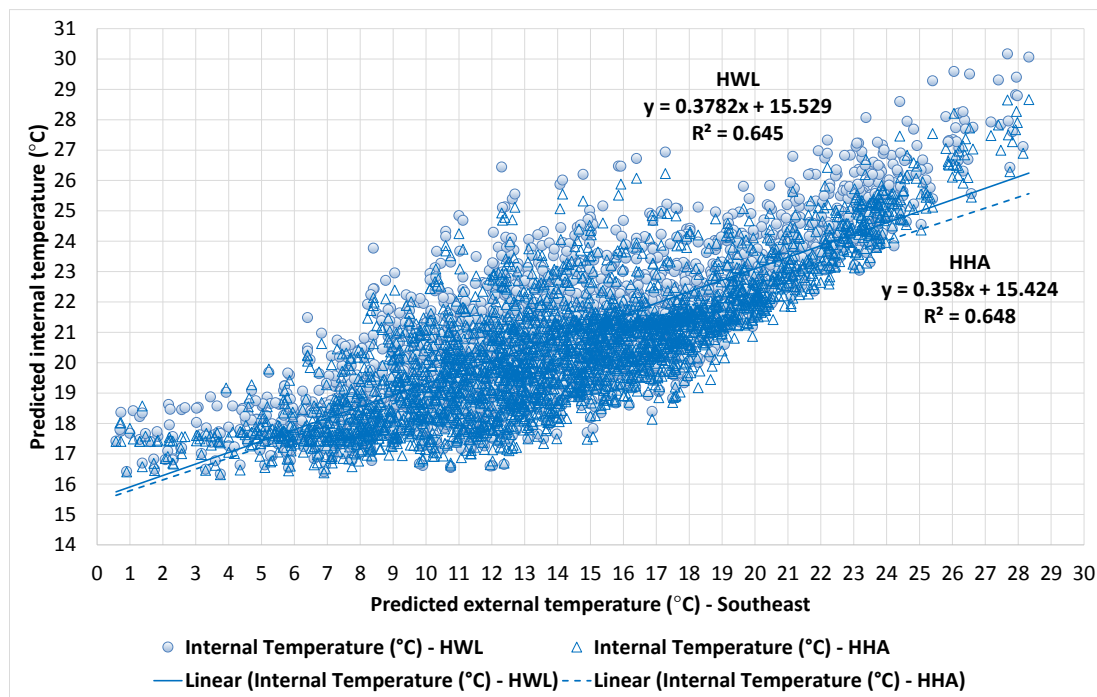


Figure 3. The relationship between the predicted internal and external temperatures (TRY 2000s - Southeast)

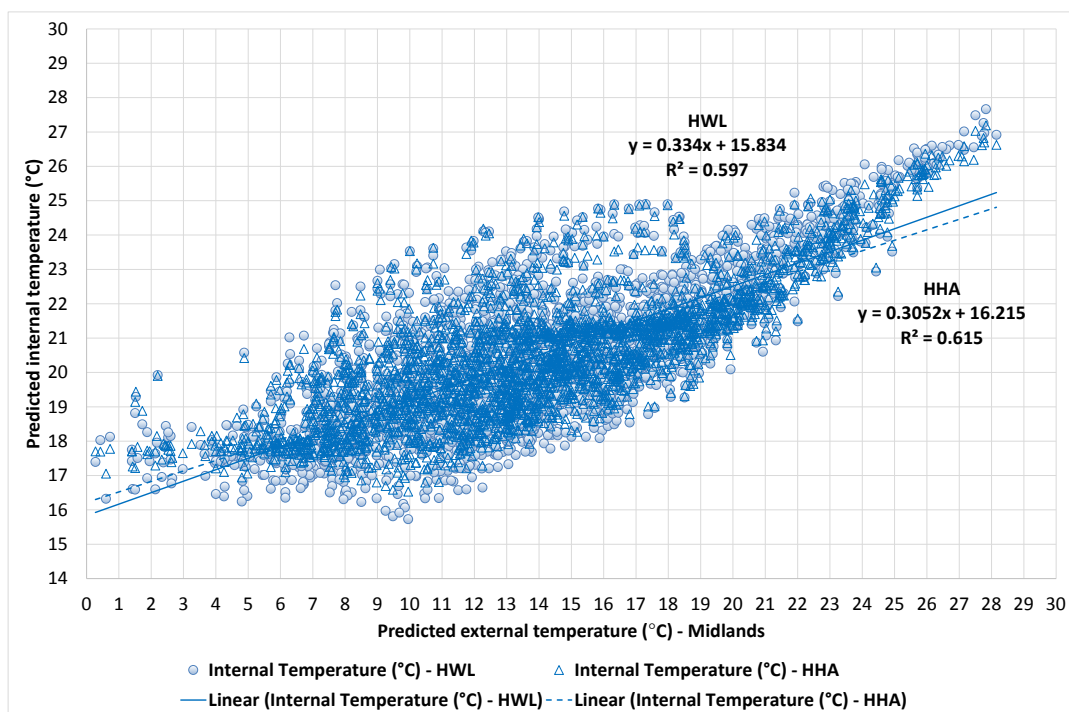


Figure 4. The relationship between the predicted internal and external temperatures (TRY 2000s - Midlands)

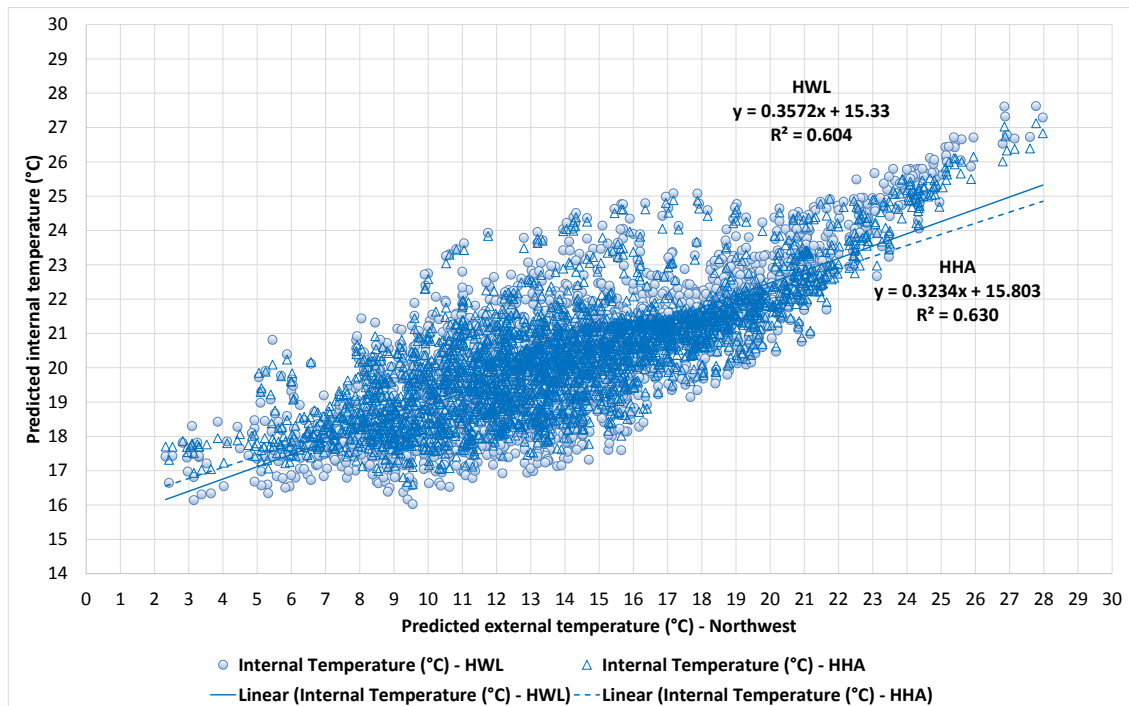


Figure 5. The relationship between the predicted internal and external temperatures (TRY 2000s -Northwest)

Table 6. Current performance (monthly) of the buildings in different regional climates

Variables	Internal Temperature (TRY 2000s)							
	HWL - Southeast				HHA - Southeast			
	May	Jun	Jul	Aug	May	Jun	Jul	Aug
Mean temp	19.4	20.9	21.8	21.5	18.9	20.4	21.3	21.3
Max. temp.	28.2	30.2	27.3	27.9	26.9	28.7	26.6	27.5
Min. temp.	16.3	16.5	17.4	18.2	16.3	16.4	17.3	17.9
Hours >25°C	12 (1.6%)	68 (9.4%)	52 (6.9%)	47 (6.3%)	8 (1.1%)	45 (6.3%)	28 (3.8%)	31 (4.2%)
Hours >28°C	1 (0.1%)	13 (1.8%)	0	0	0	4 (0.6%)	0	0
	Internal Temperature (TRY 2030s)							
	HWL - Southeast				HHA - Southeast			
	May	Jun	Jul	Aug	May	Jun	Jul	Aug
Mean temp	20.6	23.1	27.8	25.0223	20.3	22.5	25.0	24.6
Max. temp.	28.0	31.0	34.3	34.6	26.8	29.3	32.6	33.6
Min. temp.	17.1	17.9	20.6	19.5	17.3	18.1	20.4	19.7
Hours >25°C	18 (2.4%)	158 (21.9%)	437 (58.7%)	346 (46.5%)	13 (1.7%)	117 (16.3%)	373 (50.1%)	315 (42.3%)
Hours >28°C	0	37 (5.1%)	147 (19.8%)	153 (20.5%)	0	20 (2.8%)	83 (11.2%)	128 (17.2%)
	External Temperature (TRY 2000s)				External Temperature (TRY 2030s)			
	Southeast				Southeast			
	May	Jun	Jul	Aug	May	Jun	Jul	Aug
Mean temp	11.1	13.7	15.9	16.0	13.6	17.4	20.4	20.0
Max. temp.	26.4	28.3	26.1	28.2	26.6	29.3	31.4	34.0
Min. temp.	0.6	0.7	6.4	5.8	3.0	6.9	7.1	9.9
Hours >25°C	6 (0.8%)	20 (2.8%)	6 (0.8%)	10 (1.3%)	4 (0.5%)	49 (6.8%)	156 (20.7%)	156 (20.7%)
Hours >28°C	0	1 (0.1)	0	1 (0.1%)	0	19 (2.6%)	45 (6.0%)	61 (8.2%)

Note: Duration of the simulations: May – 744 hours; June – 720 hours; July -744 hours; and August – 744 hours. Temperatures above 25°C are highlighted in yellow. Temperatures above 28°C are highlighted in red.



Based on the current performance of the buildings, the study explored possible design interventions such as the increase window-to-wall ratio (WWR) and the window height (WH) to improve the future performance of the buildings using the 2030s TRY weather file. The findings revealed that the mean temperature in the Southeast is calculated to be lower by at least 0.1°C when the window-to-wall ratio (WWR) is changed from 45% to 55% and the window height (WH) is increased from 1.35m to 1.50m respectively. Four possible design interventions (WWR 45% + WH 1.35m; WWR 55% + WH 1.35m; WWR 45% + WH 1.50m; WWR 55% + 1.50m) were introduced and applied to the simulations. The results showed there is no significant improvement in the current and future performance of the buildings when the variables are changed. For instance, the predicted maximum temperatures are reduced by 0.1°C-0.4°C across the case study locations. Also, the frequency of high temperatures is predicted to be reduced by 1 hour to 6 hours. In terms of the number of hours that exceed the 25°C and 28°C thresholds, there is no significant change in the thermal environment of the buildings when the window-to-wall ratio (WWR) is increased from 45% to 55% and when the window height (WH) is changed from 1.35m to 1.5m (Table 7).

Table 7. Future performance of the buildings in the Southeast regional climate

Variables	HWL (TRY 2030s) – Southeast				HHA (TRY 2030s) – Southeast			
	WWR 45% + WH 1.35m	WWR 55% + WH 1.35m	WWR 45% + WH 1.50m	WWR 55% + WH 1.50m	WWR 45% + WH 1.35m	WWR 55% + WH 1.35m	WWR 45% + WH 1.50m	WWR 55% + WH 1.50m
Mean temp	23.6	23.5	23.5	23.3	23.1	23.0	22.9	22.8
Max. temp	34.6	34.5	34.5	34.4	33.6	33.5	33.4	33.2
Min. temp	17.1	17.0	17.0	16.8	17.3	17.1	17.1	16.9
Hours >25°C	959 (32.5%)	958 (32.5%)	958 (32.5%)	953 (32.2%)	818 (27.7%)	816 (27.6%)	816 (27.6%)	812 (27.5%)
Hours >28°C	337 (11.4%)	334 (11.3%)	334 (11.3%)	330 (11.1%)	231 (7.8%)	229 (7.8%)	228 (7.7%)	225 (7.6%)
Hours >30°C	105 (3.5%)	103 (3.4%)	103 (3.4%)	98 (3.3%)	55 (1.9%)	53 (1.8%)	53 (1.8%)	50 (1.7%)
Hours >32°C	22 (0.8%)	20 (0.7%)	20 (0.7%)	15 (0.5%)	9 (0.3%)	8 (0.3%)	8 (0.3%)	6 (0.2%)
Hours >34°C	7 (0.2%)	7 (0.2%)	7 (0.2%)	4 (0.1%)	0	0	0	0

Note: WWR (Window-to-Wall Ratio); WH (Window Height). Temperatures above 25°C are highlighted in yellow. Temperatures above 28°C are highlighted in red.

Since existing research [Adekunle, 2014] highlighted that increase in floor area (FA) and floor-to-ceiling height (FCH) may likely improve the performance of lightweight buildings, the parameters were also explored for the investigation. As a result, the floor area of the buildings (HWL and HHA) is increased by 20% (that is, from 77.0m<sup>2</sup> to 92.5m<sup>2</sup>) and the floor-to-ceiling height is increased by 15% (that is, from 2.35m to 2.70m) for the simulations. The findings revealed there is a noticeable change in the thermal environment of the buildings as the frequency of high temperatures is reduced. The lower mean temperature (at least 1.1°C) and maximum temperature (at least 1.3°C) are predicted across the case study buildings. The number of hours that exceed the critical thresholds for comfort (25°C and 28°C) is significantly reduced at both buildings. The study showed the increase in floor

area (FA) and the floor-to-ceiling height (FCH) can reduce the frequency of summertime temperatures in lightweight buildings.

The findings on energy consumption for cooling if natural ventilation is supplemented with cooling devices such as the use of cooling fan revealed the buildings are predicted to consume more energy in future. For instance, the actual amount of energy consumed at the HWL building in the summer (May-July) was 634.71kWh. However, the predicted amount of energy consumption showed higher values above the actual amount of energy used during the period when considering the future weather files. The simulations revealed the possibility of high energy demand as the global temperatures increase in order to improve the thermal environment of lightweight buildings. The results showed that sustainable lightweight buildings are predicted to use more energy especially in the future for cooling than the current scenario.

## Conclusions

The study examined the current and future performance of sustainable lightweight buildings in three regional climates (Southeast, Midlands, and Northwest in the UK). Two sustainable buildings (HWL) and (HHA) with a similar floor area (FA), floor-to-ceiling height (FCH), window height (WH) but different orientations, number of occupants, the arrangement with respect to other buildings, duration of occupancy were considered for the investigation. The research considered dynamic building simulation as a technique to evaluate the current and future performance of the buildings in summer (May 1-August 31) using the Test Reference Year (TRY) weather files for the 2000s and the 2030s. The predicted results are validated using the data obtained during the field investigation conducted at the case study buildings. The results revealed the predicted mean temperatures varied from 20.3°C to 20.8°C for the current weather scenario (that is, the 2000s TRY). Also, the simulated mean temperatures for the 2030s (TRY) varied from 23.1°C to 23.6°C. The study showed higher external and internal temperatures are predicted at the HWL and HHA buildings in the Southeast regional climate set-up than the Midlands and the Northwest regional climates set-up.

The mean temperature is predicted to be lower by at least 0.1°C when the window-to-wall ratio (WWR) is increased from 45% to 55% and the window height (WH) from 1.35m to 1.50m respectively. In the warmest region of the UK (that is, the Southeast of England), the simulated internal temperatures in summer (May-August) of the current year (the 2000s TRY) are predicted to exceed the 25°C indicator for 6.2% and the 28°C threshold for 0.5% of the time at the HWL building. The predicted internal temperatures exceeded the 25°C threshold for over 32.5% of the period and it exceeded the 28°C threshold for 11.4% of the time. The predicted mean temperature exceeded 30°C for 3.5% of the total simulated period (2952 hours) in the HWL building (that is, the warmest building). In terms of the number of hours that exceeded the critical thresholds for thermal comfort of occupants (25°C and 28°C), there is no significant change in the thermal environment at the case study buildings when the window-to-wall ratio (WWR) is increased from 45% to 55% and when the window height (WH) is changed from 1.35m to 1.50m. However, a significant change in the thermal environment of the buildings is predicted when the floor area is increased by 20% and the floor-to-ceiling height (FCH) by 15%. The study revealed sustainable lightweight buildings are prone to high temperatures under current and future weather scenarios even when the buildings are located in regions with cooler summertime and milder wintertime. The study also identified that the future performance of sustainable lightweight buildings can be improved using various design interventions (such as an increase in the floor area

and higher floor-to-ceiling height). In addition, the study showed the possibility of crucial design variables that can have a significant result in improving thermal comfort of occupants in lightweight buildings. It is also important to highlight that some variables can also exhibit no significant improvement regarding occupants' comfort in the buildings if the variables are not well adjusted or if the modelling and simulation are not well executed. Finally, the study highlighted that sustainable lightweight buildings are likely to use more energy in future for cooling than the current scenario. This is a critical issue that requires further research to understand energy-load distribution during high demand period in sustainable lightweight buildings.

## References

- Adekunle, T.O. (2014). *Thermal Performance of Low-carbon Prefabricated Timber Housing in the UK*. PhD Thesis. University of Kent, UK
- Adekunle, T., Nikolopoulou, M. (2014). Post-occupancy and indoor monitoring surveys to investigate the potential of summertime overheating in UK prefabricated timber houses. In *Proceedings of Windsor Conference 2014: Counting the Cost of Comfort in a changing world*, Cumberland Lodge, Windsor, UK, April 10 – 13. London: Network for Comfort and Energy Use in Buildings (NCEUB), London.
- Adekunle, T.O., Nikolopoulou, M. (2016a). Thermal comfort, summertime temperatures and overheating in prefabricated timber housing. *Building and Environment*, 103, 2016, pp. 21-35
- Adekunle, T.O., Nikolopoulou, M. (2016b). Thermal performance of indoor spaces of prefabricated timber houses during summertime. In *Proceedings of 9<sup>th</sup> Windsor Conference 2016*, UK. April 7-10. London: Network for Comfort and Energy Use in Buildings (NCEUB), London.
- Chartered Institution of Building Services Engineers (2006). *Environmental Design: CIBSE Guide A*, 7th ed.; CIBSE: London, UK.
- Chartered Institution of Building Services Engineers (2010). *How to manage overheating in buildings: a practical guide to improving summertime comfort in buildings*. CIBSE Knowledge Series. CIBSE: London, UK.
- DesignBuilder (2010). *DesignBuilder Simulation*. <https://www.designbuilder.co.uk/designbuilder-sbem-approval>. Accessed on 23/09/17.
- Herrera H., Natarajan, S., Coley, D.A., Kershaw, T., Ramallo-González, A.P., Eames, M., Fosas, D., Wood, M. (2017). A review of current and future weather data for building simulation. *Building Serv. Eng. Res. Technol.* 2017, 38(5), pp. 602–627
- International Energy Agency – IEA (2012). *World: [Energy] Balances for 2012*.
- Kendrick, C., Walliman, N. (2007). Removing unwanted heat in lightweight buildings using phase change materials in building components: simulation modelling for PCM plasterboard. *Architectural Science Review*, 50(3), pp. 265-273.
- Long, X., Zhang, W., Li, Y., Zheng, L. (2017). Thermal performance improvement of lightweight buildings integrated with phase change material: An experimental and simulation study. *Advances in Mechanical Engineering*, 9(6), pp. 1-8
- Papadopoulos, Y., Soebarto, V. (2015). Investigation of thermal comfort and airflow in a naturally ventilated lightweight house in a bush fire prone area. In *Proceedings of 14<sup>th</sup> Conference of International Building Performance Simulation Association (IBPSA) 2015*, Hyderabad, India, Dec. 7-9
- Yin, H., Cong, Z., Ahmed, A., Tumwesigye, E., Menzel, K. (2010). Building performance analysis based on modelling and simulation. In *Proceedings of the International Conference on Computing in Civil and Building Engineering 2010*. Nottingham University Press
- Yoshimi, J., Altan, H. (2011). Thermal simulations on the effects of vegetated walls on indoor building environments. In *Proceedings of 12<sup>th</sup> Conference of International Building Performance Simulation Association 2011*, Sydney, November 14-16

# Assessing the Impact of Degree Day Base Temperatures on The Development of an Energy Index to Measure Energy Reduction

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**Abstract:** Refurbishment projects must be monitored before and after technology or behavior changes implementations to be able to assess their effectiveness and to drive conclusions on their applicability. An Energy Index approach has been previously developed and at its foundation, is the implication of base temperature selection on Degree Day for assessing energy reduction. The base temperature used to calculate Degree Days in the UK is 15.5 degrees.

The aim of this study was to assess the impact of Degree Day base temperatures on the development of an Energy Index by means of correlation between energy consumption and Degree Days.

The methodology was based on a low budget energy management strategy, in which the following information was collected: meter readings, internal temperature and outdoor conditions by means of degree-days. The methodology was employed in thirteen flats, with a control group of six flats having electric storage heaters and a further seven flats retrofitted with heat pumps. The flats were retrofitted with heat pumps; meter readings were collected around monthly intervals, while internal temperature was collected at 20 minutes intervals. Energy consumption was correlated to Degree Days based on 15.5 degrees and then compared to the correlation when the base temperature for Degree Days matches the internal flat temperature.

The results show that by matching the base temperature to internal flat temperature, the average correlation improves from 0.55 to 0.76 and the average standard deviation improves from 0.36 to 0.19, meaning that the spread of results is reduced and a better evaluation of refurbishment technology or behavior changes can be achieved. The control group, with electric heater storages, experiences the greater correlation and standard deviation improvements.

Matching the Degree Day base temperature to the internal temperature allows a more realistic accountability for the energy consumption to assess refurbishments by the Energy Index.

**Keywords:** Degree Day, Base temperature, Energy Consumption, Energy Reduction

## Introduction

If the true benefits of refurbishment implementation need to be understood, then refurbishment projects must be monitored before and after technology or behavior changes implementations to be able to assess their effectiveness and to drive conclusions on their applicability. An Energy Index approach has been previously developed (Jimenez-Bescos, 2015) and at its foundation, is the implication of base temperature selection on Degree Day for assessing energy reduction.

Degree Days have been used for some times and its calculation well explained (CIBSE, 2006 and Krarti, 2012). Although originally used in agriculture, the use of Degree Days are nowadays used as a forecasting tool for energy demand (Hong, 2013). Degree Days are widely used to forecast the energy demand of a house in the future or for normalising energy meter readings to allow for comparisons between different years. For example, the energy use during the month of February will be different each year in accordance to a soft winter or a hard winter. Degree days records the severity of softness of the weather and allows us to compare different years after normalisation. Furthermore, Degree Days can be used to estimate the energy demand of regions or communities (Mitchell, 1987)

A key aspect for the calculation and use of Degree Days is the base temperature or balance point temperature (Layberry, 2008). According to Layberry (2009), plotting energy use versus Degree Day will generate a straight line when the base temperature is correct.

Due to the importance of the base temperature to calculate the correct Degree Days, methodologies have been developed to calculate the base temperature, as presented by Day et al (2003). Some of these methodologies rely on the calculation of the building energy signature, as presented by Krese et al (2012), which involves plotting daily electrical consumption versus mean daily temperature. As subjected by the author, the main disadvantage is the requirement of high resolution consumption data.

The base temperature for Degree Days in the UK is taken as 15.5 degrees, although the true base temperature can oscillate (Walsh, 1993). Chosen the wrong base temperature will introduce an error in the Degree Day calculation (Woods and Fuller, 2014).

The aim of this study was to assess the impact of Degree Day base temperatures on the development of an Energy Index by means of correlation between energy consumption and Degree Days.

## Research Methods

The methodology was based on a low budget energy management strategy, in which the following information was collected: meter readings, internal temperature and outdoor conditions by means of Degree Days as presented in Jimenez-Bescos (2015). The methodology was employed in thirteen flats in total, containing a control group of six flats, in building one, having electric storage heaters and a further seven flats, in building two and three, which were retrofitted with air source heat pumps. A control group was used due to unavailability of data during the pre-retrofit period due to data lost in the monitoring process. This is one of the main challenges dealing with monitoring as presented by (Jimenez-Bescos, 2016). The thermal envelope of the three buildings was outside the scope of the project but data collection visit highlighted that a fabric first approach should have been taken prior to retrofitting air source heat pumps. The buildings fabric, at least walls and roof insulation, would have benefit from improvement and airtightness levels were quite low producing a very leaky envelope, which was less than ideal for an air source heat pump installation.

For all the flats, meter readings were collected at roughly monthly intervals, while internal temperature was collected at 20 minutes intervals. The internal temperature was average to a daily value to be used as base temperature to calculate Degree Days. Furthermore, the internal temperature was average across the dates between meter readings. Energy consumption was correlated to Degree Days based on two different approaches:

- Following a base temperature of 15.5 degree centigrade.
- A base temperature for Degree Days matching the internal flat temperature as a daily average.

The coefficient of determination,  $R^2$ , was used to assess the correlation between energy consumption and Degree Days. The coefficient of determination expresses how much the dependency of the dependent variable, energy consumption, can be explained by the independent variable, Degree Days (Bryman, 2004). The coefficient of determination will vary between a value of 0 and 1, the closer to 1 the stronger the correlation between the variables. A value closer to 0 indicates no relationship of any significance between variables. It must be noted that a strong correlation does not imply cause and effect (Collis and Hussey, 2003).

The Degree days were calculated on a daily basis in accordance to the two base temperature approaches, 15.5 degree centigrade and internal temperature, and added together following the interval of meter reading.

## Results

The results presented in Table 1 and Figure 1 show that, by matching the base temperature to internal flat temperature, the average correlation for all the thirteen flats improved from 0.55 to 0.76 and the average standard deviation improved from 0.36 to 0.19, meaning that the spread of results is reduced and a better evaluation of refurbishment technology or behavior changes can be achieved. The level of correlation was improved from slightly statistical significant to a good correlation between energy consumption and Degree Days calculated by matching the base temperature to the internal temperature of the flats. The most important detail regarding the improved correlation is not related to increasing the value and getting closer to 1, but to be able to capture and understand that in many cases such as flats 3 and 11, the use of energy can be understood and compare to the other flats. It must be noted that in some cases, for example flats 4 and 10, the correlation value is reduced but still keeping reasonable levels of strong correlation.

Table 1. Coefficient of Determination ( $R^2$ ) for the thirteen flats for base temperatures of 15.5 degrees and internal temperature.

<b>R2</b>	<b>15.5 Degree</b>	<b>Int Temp</b>
<b>Flat 1</b>	0.8535	0.8368
<b>Flat 2</b>	0.4826	0.9273
<b>Flat 3</b>	0.0003	0.7753
<b>Flat 4</b>	0.9905	0.8842
<b>Flat 5</b>	0.6706	0.5502
<b>Flat 6</b>	0.1186	0.3886
<b>Flat 7</b>	0.7058	0.9222
<b>Flat 8</b>	0.6338	0.9342
<b>Flat 9</b>	0.6212	0.6821
<b>Flat 10</b>	0.9497	0.8126
<b>Flat 11</b>	0.053	0.4722
<b>Flat 12</b>	0.9651	0.9655
<b>Flat 13</b>	0.1868	0.7944
<b>Average</b>	0.5563	0.7650
<b>SD</b>	0.3583	0.1877

Table 2 shows the coefficient of determination,  $R^2$ , split between electric storage heaters (control group) and air source heat pump. The control group with electric heaters was showing a lower correlation average at roughly 0.5, while the group with air source heat pumps presented a correlation of about 0.6 for a base temperature of 15.5 degree centigrade. It must be noted that by using the internal temperature as base temperature for the Degree Days calculations, both groups, electric storage heaters and air source heat pump users, achieve a very similar correlation average of 0.76.



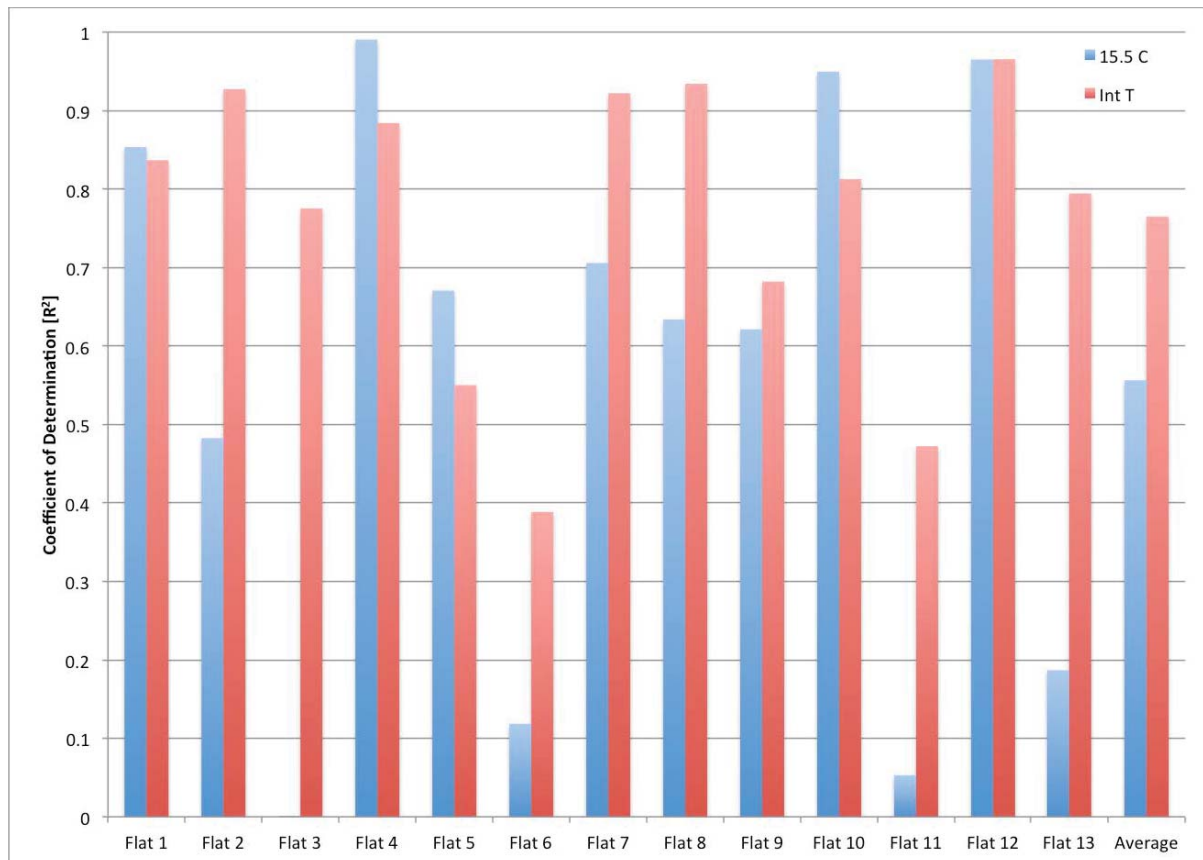


Figure 1. Coefficient of Determination ( $R^2$ ) for the thirteen flats for base temperatures of 15.5 degrees and internal temperature.

Table 2. Coefficient of Determination ( $R^2$ ) in accordance to heating method.

Electric Storage Heaters			Air Source Heat Pump		
R2	15.5 Degree	Int Temp	R2	15.5 Degree	Int Temp
<b>Flat 7</b>	0.7058	0.9222	<b>Flat 1</b>	0.8535	0.8368
<b>Flat 8</b>	0.6338	0.9342	<b>Flat 2</b>	0.4826	0.9273
<b>Flat 9</b>	0.6212	0.6821	<b>Flat 4</b>	0.9905	0.8842
<b>Flat 10</b>	0.9497	0.8126	<b>Flat 5</b>	0.6706	0.5502
<b>Flat 3</b>	0.0003	0.7753	<b>Flat 6</b>	0.1186	0.3886
<b>Flat 11</b>	0.053	0.4722	<b>Flat 12</b>	0.9651	0.9655
			<b>Flat 13</b>	0.1868	0.7944
<b>Average</b>	0.4940	0.7664	<b>Average</b>	0.6097	0.7639
<b>SD</b>	0.3812	0.1722	<b>SD</b>	0.3584	0.2139

## Discussion

The results presented in Table 1 and 2, as well as Figure 1, support the importance of the base temperature to calculate the correct Degree Day, as stated by Layberry (2008). Suggesting that the used of internal temperature as a base temperature will provide a closer match to an straight line when plotting energy versus Degree Days, as suggested by Layberry (2009), by having a closer to 1 value for the coefficient of determination ( $R^2$ ) and showing a stronger correlation between energy consumption and Degree Days. The improvement is well appreciated in flats 3 and 11, where it can be attributed to the difference between internal temperature of the flat and the standard base temperature of 15.5 degrees centigrade.

While some of the methodologies to calculate the base temperature, such as the building energy signature (Krese et al, 2012), will have some issues related to the resolution of the data collected, the use of the internal temperature will be relatively easy to monitoring and store by means of a data logger. In the awakening of the Internet of Things (IoT) and a growing number of sensors and data loggers around the house, providing a means to measure and store internal temperature is quite straightforward and will results in a more accurate calculation of the Degree Days by selecting the correct base temperature and avoiding errors (Woods and Fuller, 2014).

Comparing the correlations by using the stipulated base temperature of 15.5 degree centigrade or the internal temperature as base temperature, it can be observed that a better match between the energy consumption and Degree Days can be achievable and as a result, better energy demand projections can be estimated from these correlations.

The findings in this paper support the use of the internal temperature of properties as base temperature to calculate more accurate Degree Days. This methodology has been developed as an energy index (Jimenez-Bescos, 2015) to provide a more accurate approach to compare heating energy performance of different properties for non professional people and to make initial judgements on performance by technology improvements and/or user behaviour measures.

The energy index methodology has been successfully applied to a retrofit case in the United Kingdom, in which air source heat pump combined with user behaviour measures were deploying to reduce energy use and carbon emissions (Jansson-Boyd, 2016). By using internal temperatures as base temperatures for the Degree Days calculation a more accurate energy use profile was developed to evaluate the benefits of energy efficiency measures.

## Conclusion

Matching the Degree Day base temperature to the internal temperature allows a more realistic accountability for the energy consumption to assess refurbishments by the Energy Index. Providing support for the use of an energy index methodology to normalized the energy use consumption data for easy comparison across properties, seasons and locations.

## References

- Bryman, A. (2004). *Social Research Methods*. Oxford University press.
- CIBSE. (2006). *TM41 Degree-days: theory and application*. CIBSE Publications.
- Collis, J. and Hussey, R. (2003). *Business Research*. Palgrave.
- Day, A.R., Knight, I., Dunn, G. and Gaddas, R. (2003) Improved methods for evaluating base temperature for use in building energy performance lines. *Building Serv. Eng. Res. Technol*, 24 (4), pp. 221-228.
- Hong, W. (2013). *Intelligent energy demand forecasting*. Springer.
- Jansson-Boyd, C., Robison, R., Cloherty, R. and Jimenez-Bescos, C. (2016) Complementing retrofit with engagement: exploring energy consumption with social housing tenants. *International Journal of Energy Research*, 41 (8), pp. 1079-1222.
- Jimenez-Bescos, C. (2015) The Development of an Energy Index to Assess Energy Reduction. *Selected Papers from the International SEEDS Conference*, pp. 293-298. LSI Publishing.
- Jimenez-Bescos, C. (2016) The Challenges Of Monitoring Energy Consumption To Assess Behavioural Changes In Occupants During Renovation Projects From A Low Budget Point Of View. *Energy Procedia*, 96, pp. 916-922.
- Krarti, M. (2012). *Weatherization and energy efficiency improvement for existing homes – an engineering approach*. CRC Press.
- Krese, G., Prek, M. and Butala, V. (2012) Analysis of Building Electric Energy Consumption Data Using an Improved Cooling Degree Day Method. *Journal of Mechanical Engineering*, 58 (2), pp. 107-114.
- Layberry, R.L. (2008) Degree days for building energy management – presentation of a new data set. *Building Serv. Eng. Res. Technol*, 29 (3), pp. 273-282.
- Layberry, R.L. (2009) Analysis of errors in degree days for building energy analysis using Meteorological Office weather station data. *Building Serv. Eng. Res. Technol*, 30 (1), pp. 79-86.
- Mitchell, J.M. (1987) Degree Days: Heating and Cooling by the Numbers, *Weatherwise*, 40 (6), pp. 334-336
- Walsh, P.J. (1983) The relation between degree days and base temperature. *Applied Energy*, 13, pp. 241-253.
- Woods, J. and Fuller, C. (2014) Estimating base temperatures in econometric models that include degree days. *Energy Economics*, 45, pp. 166-171.

# Argumentations of Visual Comfort Metrics in Dynamic Day Lit Spaces

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**Abstract:** *"Natural light is the only light, because it has mood... it puts us in touch with the eternal. It is the only light that makes architecture."*- Louis Khan.

Daylight is one key aspect to enhance the sense of place and influence the personal interpretations and impressions that last long after leaving the place. However, visual discomfort and glare can distract architects from achieving the most of daylighting. To better achieve visual comfort in dynamic daylight spaces the time and space dynamics of the daylight condition, and the representation and re-imagining of these dynamics need to be considered.

This paper examines logical argumentation through the exploration of various visual comfort metrics. The argument investigates several factors that affect visual performance and occupants comforts. Some of these factors include lighting level, uniformity of illuminance, color rendering, avoiding hard shadows, contrast rendition, physiological glare, balanced brightness distribution, luminance levels variation, discomfort glare, illuminance uniformity in the area around the visual task, and the balance between artificial lighting and daylight. The argumentation concludes a compilation of different visual comfort evaluation metrics. These metrics aim to consider the two key dynamics of daylighting; time and movement through spaces to achieve the most adequate daylighting performance with the most visual comfort. The research outcomes are expected to provide researchers, designers, and decision makers with a new approach to designing spaces to improve visual comfort, energy performance and the quality of the place.

**Keywords:** Occupants comfort, Daylighting, Visual comfort.

## Introduction

Arguments are chains of reasons leading to a conclusion with consideration of potential counterarguments at each step (Kleindienst and Andersen, 2009). They are capable to present knowledge and common sense reasoning. The foundation of a logical argument is its intention, or the proposition is either true or false (i.e. accurate or inaccurate). For a logical argument to be valid, it needs to follow three stages: premises, inference, and conclusion.

A. Premises: Premises are the necessary propositions for the argument to continue. They are indicated by phrases such as "because," "since," "obviously," etc.

B. Inference: The inference is the process of using the arguments to obtain further propositions. They are indicated by phrases such as "implies that" or "therefore."

C. Conclusion: The conclusion is the final stage of inference. It affirms the argument on the basis of the premises and the inference. Conclusions are often indicated by phrases such as "therefore," "it follows that," "we conclude," etc. (Bellia et al., 2011, Budde et al., 1992).

In this research, the logical argumentation main goal is to argue for the selection of thresholds for design criteria and decision support metrics for visual comfort.

## Methodology

According to arguments stages, the paper is divided into 1) identification of the argumentation method, 2) presentation of the evaluation metrics, categorization of the metrics and glare and setting visual comfort thresholds 3) arguing for the selection of each metric and its applied threshold 3) conclusion of the argumentations, 4) testing of the

argument findings and conclusion using a case study of a typical office space where the selected metrics and their thresholds are applied, and 5) final conclusions of the case study are generated in addition to the paper findings and contribution in the design decision-making process.

### Visual Comfort Evaluation Metrics Argument

Several factors affect visual performance, including lighting level, uniformity of illuminance, colour rendering, avoiding hard shadows, contrast rendition, physiological glare, balanced brightness distribution, luminance levels variation, discomfort glare. The literature found that researcher cannot depend on a single metric to investigate all the aspects of visual discomfort, Figure 1. Moreover, most of the indices examined in previous research were devoted to predicting light distribution, glare phenomena and light quality, (Carlucci et al., 2015), consequently, metrics representing these different aspects were used.

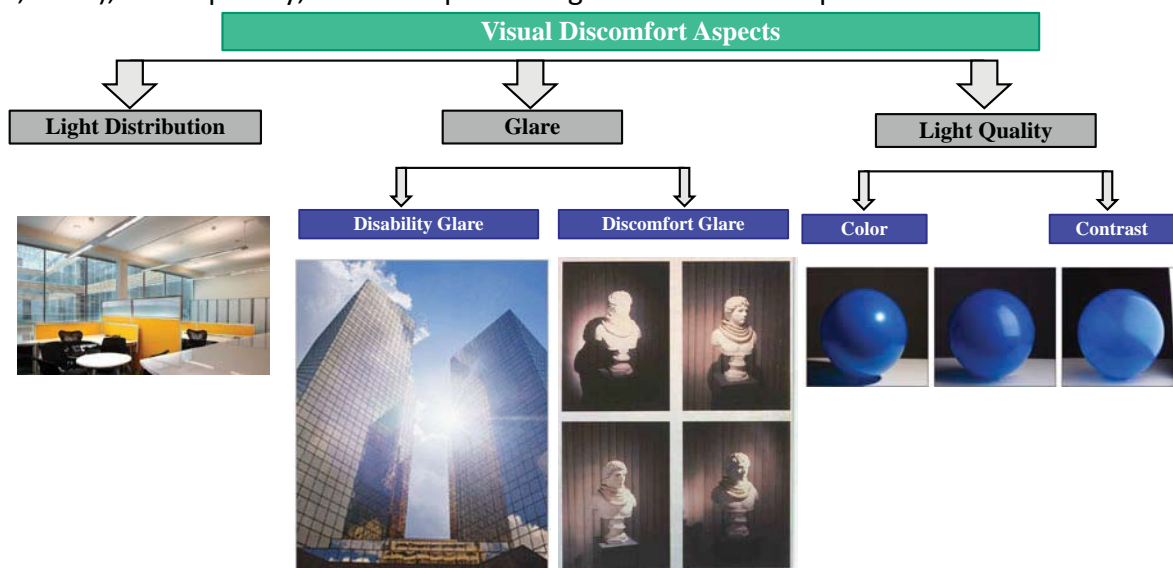


Figure 1: Visual discomfort examined aspects

Regarding visual comfort evaluation metrics argument, the Useful Daylight Illuminance UDI and illuminance value distribution were used to evaluate the light distribution in the space. For light quality, the luminance ratio was used. Finally, for glare evaluation metrics the Daylight Glare Probability (DGP) and the Daylight Glare Index (DGI) were used, as shown in Figure 2 and argued in the following sections.

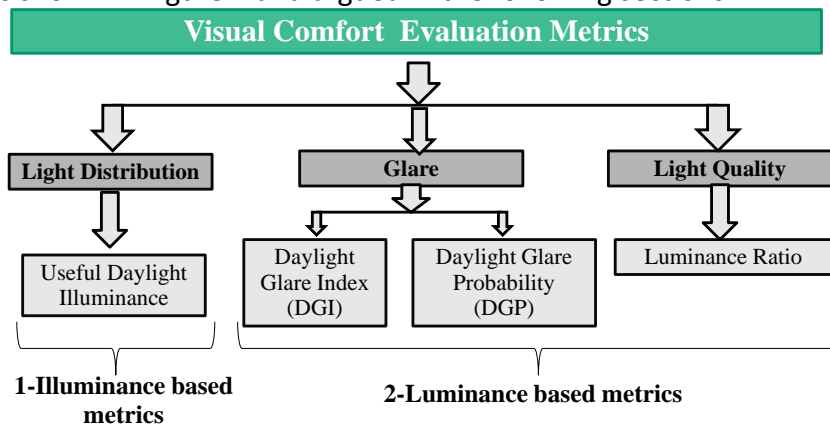


Figure 2: Visual comfort evaluation metrics

### *Light distribution: Illuminance based metrics*

Because short execution times are necessary to provide feedback and decision-support promptly to the designer during the early stages of design, and because illuminance simulations consume less computing time when compared with luminance image simulations, illuminance metrics were applied as the first step for visual comfort evaluation.

- *Useful daylight illuminance (UDI)*

Because the Useful Daylight Illuminance can quantify both over-lit and under-lit conditions, it can provide valuable information on the light distribution in the space. Consequently, UDI can be suitable for both short and long-term evaluation—especially when excessive sunlit penetration may cause intense glare. Because UDI is based on spatial renderings for every point on the calculation grid, it can be used to ensure that all of the simulation points meet the illuminance guidelines as suggested by Yin (2008). For the first version of the tool, UDI was tested on the solstices and equinox days only.

### *Glare: Luminance based metrics*

The luminance evaluation took place for the peak illuminance areas and times. Future versions of the tool may utilize hourly luminance calculations as computer processing speeds increase. However, due to the limitations of current processor speeds available, results are based on the peak condition(s)-only simulations for the tool. The process of identifying glare conditions requires the implementation of one or more metrics with associated threshold levels. The following sections argue for the luminance metrics used in more detail.

- *Daylight Glare Probability (DGP)*

Because comfort is defined according to user satisfaction and glare is a relative sensation and differs from one person to another, then probability distribution is a reasonable approach for predicting comfort. Because the literature review showed a strong correlation between the DGP and the occupants satisfaction, the DGP was used as a visual comfort indicator in the prototype.

- *Daylight Glare Index (DGI)*

Daylight Glare Index (DGI) is a visual comfort metric that considers large glare sources (e.g. the sky viewed through a window). Because the DGI can be calculated using the Evalglare software based on the luminance of the image, date/time and sky conditions, and the materials properties of the interior finishes, and because the DGI can be normalized and compared with the overall DGP average as shown in Table 1 (Jakubiec and Reinhart, 2011), it was used in the prototype for an easier representation of the glare condition.

Table 1: DGI thresholds

DGI-effect	imperceptible	Perceptible	disturbing	intolerable
Value	< 18	18 – 24	24 – 31	> 31
Normalized value (*0.01452)	<0.26136	0.26136-0.34848	0.34848-0.45012	>0.45012

### *Light quality: Luminance based metrics*

Since light color and contrast are two main factors affecting the light quality, and since the light quality indexes that evaluate the color are typically used to only evaluate artificial lighting, their main reference light is daylight (i.e. Color rendering index, Color Rendering



Capacity, Pointer's color, Color Preference Index, and Color Rendering Capacity) (Thornton, 1972); (Xu, 1984); (Pointer, 1986, Barbrow, 1964). Image contrast was used as a metric for daylight quality evaluation.

- Luminance ratio

Previous research identified several luminance ratio guidelines applied to the three zones of the visual field (central, adjacent, and the non-adjacent). From this including luminance ratios of 1:3:10 identified by Osterhaus (2002), while Linney (2008) and Parpaire et al. (2002) argued that occupants can tolerate a ratio of 1:40 and up to 1:100 between the central zone and the surroundings, and a ratio of 1:3 for the visual task and immediate surroundings. Of these, this research used the ratio of 1:3:10 as a threshold value.

#### *Used metrics argument conclusion*

From the argument, multiple evaluation metrics were used: Useful Daylight Illuminance and Illuminance distribution were used as illuminance evaluation metrics. The DGP, DGI, and luminance ratio were used for luminance image evaluation. Also, visual renderings were employed in this research for visual representation and re-imagination of the examined space.

#### **Testing The Arguments**

In order to test the arguments success and adequacy a case study was tested. For the case study, a typical side daylight office space was examined. A 3D model was generated for a single office space (15Ft. X 9Ft.) (4.6m X 2.7m) with one west-facing window (6Ft. X 3Ft.) (1.8m X 0.9m) and a 3-foot (0.9m) wide corridor as shown in Figure 3:



Figure 3: The selected office design

To generate the examined space, input into the 3D model were the geographical location, sky conditions, simulation of days and times, material properties, building geometry and simulation points as shown in Table 2:

Table 2: Case study data input

Variable	Examined Case Properties
Geographical location	San Francisco weather file was used for this case.
Sky condition	Clear sky without sun+ Clear sky with sun
Date and time (mm dd):	Default-annual- (one-hour interval)
Material properties	Generic materials were used (as shown in Table 3)
Building orientation	The 3D model was rotated to match Rhino default orientation
Building geometry (3D-model)	A 3-D model was generated in Rhino
Surroundings	No surroundings were proposed

Simulation points	Points were positioned in the office 3D-model circulation corridor
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### **Material properties**

From the 3D model inputs, material properties were further specified by location. Generic material properties from Radiance were used in the 3D-model simulations, Table 3.

Table 3: Materials properties

Item	Material
Ceiling	Generic ceiling-80% reflectance
Interior Floor	Generic floor-20% reflectance
Interior Wall	Generic interior wall-50% reflectance
Outside façade	Outside façade-35% reflectance
Outside ground	Outside ground-20% reflectance
Glass	Single pane clear-90% transmittance
Window Frame	Grey metal-50% reflectance

### **Occupants' circulation**

Simulations were performed corresponding to two eye-levels: 1) the first set of points were placed horizontally along the circulation path at 4.5-foot (1.4m) intervals and vertically corresponding to standing/walking conditions at 5.5 feet (1.8m, and 2) the second set of simulation points were set at a sitting/working position at the average eye-level at 3.3 feet (1m) and vertically at equal spacing 4.5 feet (1.4m) as shown in Figure 4.

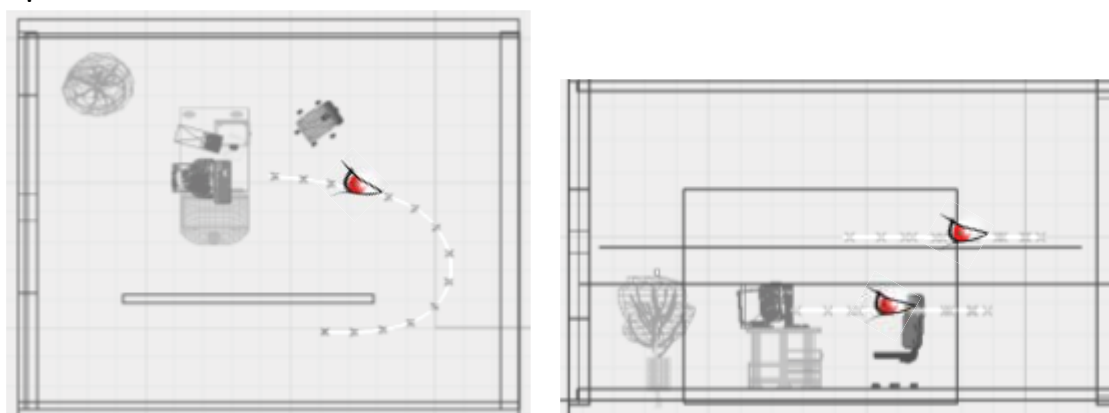


Figure 4: Simulation points and examined views in plan and section view

### **Evaluation Process**

Based on the argument the visual comfort evaluation metrics were categorized into 1) illuminance based, or “the light distribution” (i.e. Useful Daylight Illuminance, UDI and hourly illuminance distribution on the peak days) and 2) luminance-based glare problems (i.e. the Daylight Glare Index, DGI and the Daylight Glare Probability, DGP) in addition to the quality of light and contrast problems (i.e. the luminance ratio). Illuminance-based simulations were generated at each stationary point along the path, followed by image-based luminance simulations—as shown in Figure 5 and discussed in details in the following sections.

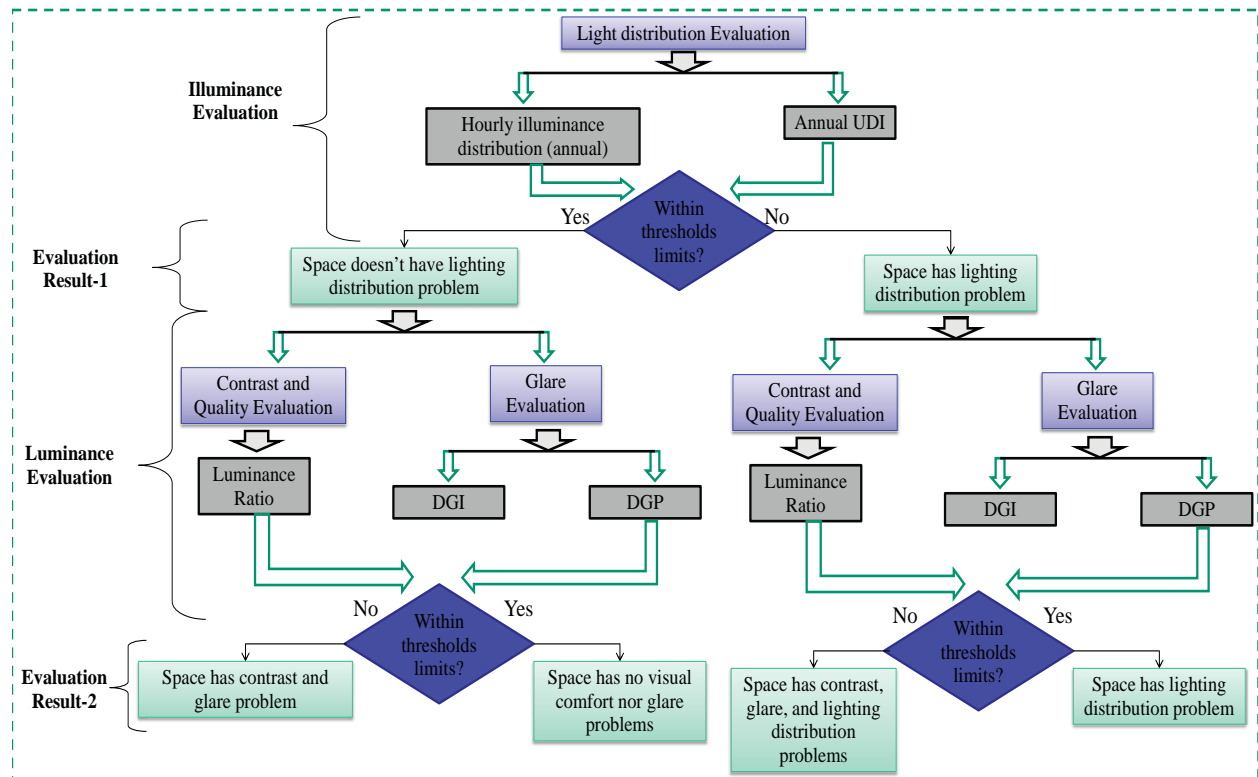


Figure 5: Evaluation process

### Base case evaluation

From the base case evaluation, several problems were detected. These included direct glare zones in the occupants visual field, high contrast in the field of view, and overall poor light quality in the space, especially in the standing position. Moreover, illuminance distribution evaluation showed some light distribution problems. However, the luminance-based evaluation metric (DGP) showed imperceptible glare conditions. Based on the initial evaluation, a number of design alternatives were proposed to solve the visual discomfort and glare problems. Only the standing position visual field was to be examined in the alternatives.

### Identifying alternatives

Design alternatives aim to improve visual comfort in the space. Five design alternatives were proposed and examined to solve the problems: Alt-1: alerted window size; Alt-2: exterior shading; Alt-3: altered glazing properties; Alt-4: interior wall finish; and finally Alt-5: an interior removable device was tested. The detailed alternatives properties and visualization images are shown in Table 4.

Table 4: Generic case design alternatives

Case name	Dimensions	Properties
<b>Base Case</b>	9x15 ft. (4.6m X 2.7m) room with a 6x3 ft. 2mX1m window (sill at 3ft. 1m)	As shown in Table 3
<b>Alt-1 window size</b>	Window 4x2 ft. 1.2m X 0.6m (sill at 3ft 1m.)	Same as the base case (Single pane clear-90% transmittance)

Case name	Dimensions	Properties
<b>Alt-2 exterior shading</b>	6 ft. 2m solid exterior shading, 6 in thick.	Generic -20% reflectance
<b>Alt-3 glazing</b>	Same as the base case 6x3 window (sill at 3ft.)	Tinted-40% transmittance
<b>Alt-4 interior shading</b>	Interior roller shades same as window size (6x3ft.)	Generic - 50% reflectance
<b>Alt-5 interior wall color</b>	Interior wall finish color changed to dark brown RGB (0.01-0.003-0.001)	Interior wall finish color RGB (0.01-0.003-0.001)

### Choosing among alternatives

The second domain of decisions was concerned with the comparison of design alternatives. The comfort metrics (including the daylight distribution, light quality and glare) were compared for the five design alternatives. Changes in visual comfort were observed as shown in Figure 6 and are discussed in the following sections.

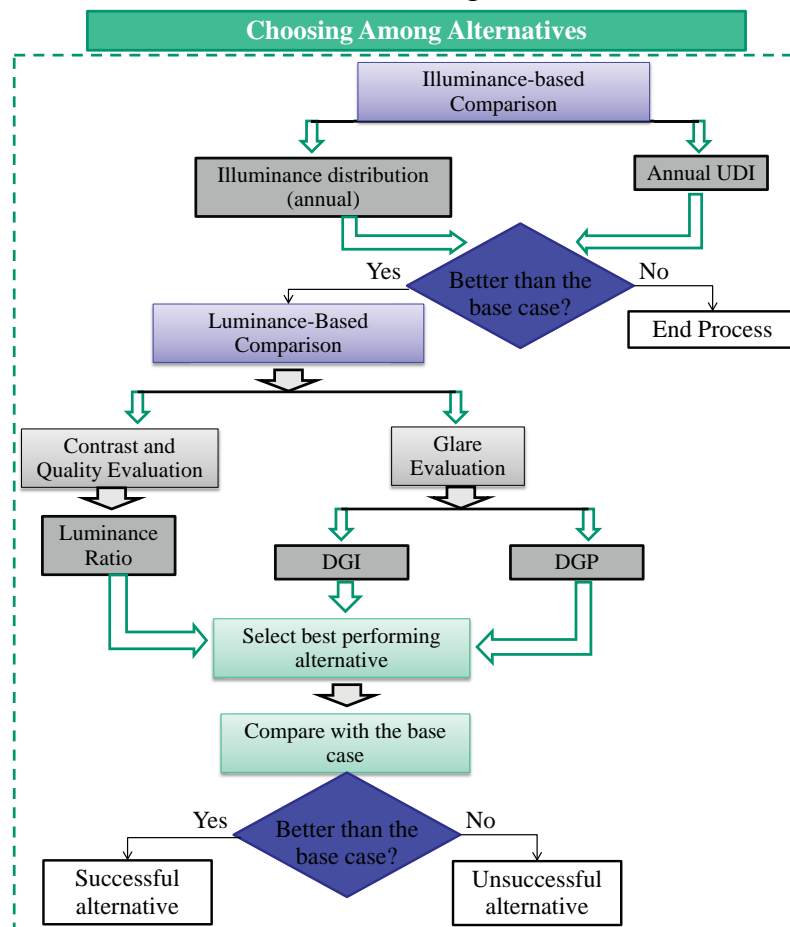


Figure 6: Choosing among alternatives

- Illuminance indexes comparison of the alternatives

A comparison between the Useful Daylight Illuminance (UDI) of each base case and its proposed alternatives is shown in Figure 7. It was concluded that all alternatives applied

showed better performance when compared to the base case, except when changing the wall surfaces' reflectivity. The best performance took place when an external shading (Alt.2) was added to the office window (UDI= 64%).

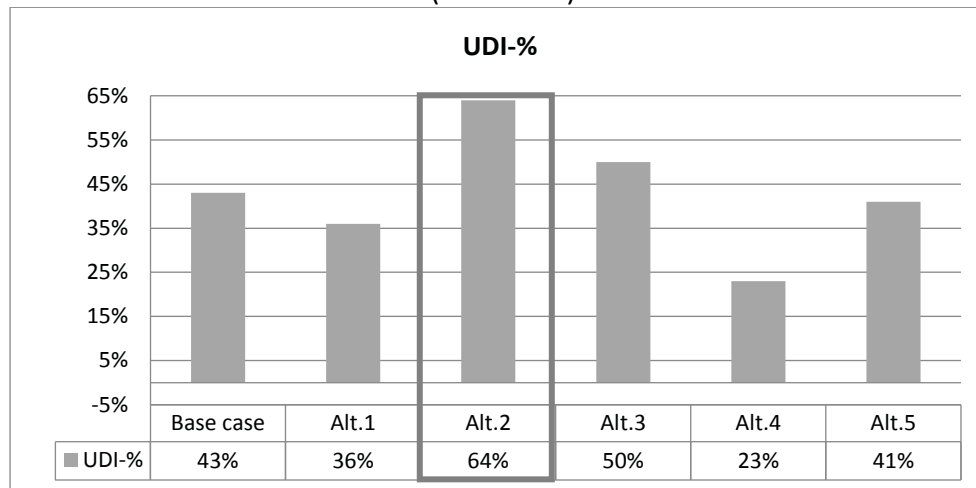
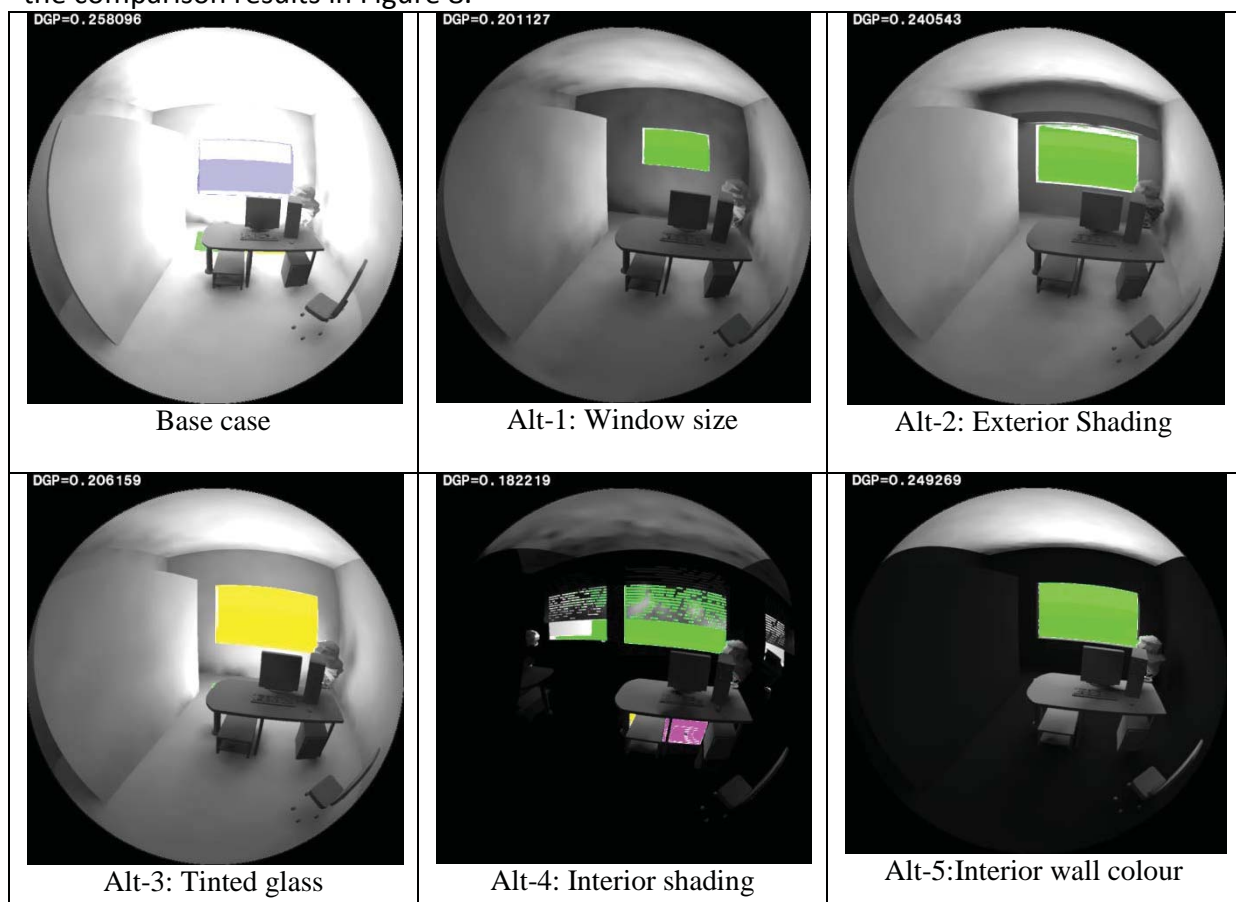


Figure 7:UDI comparison

- [Luminance indexes comparison of the alternatives](#)

The comparative results of the path images intended to help the designer in the selection among the design alternatives.

The results indicated that Alt.1-window size, Alt.2-external shading, and Alt3-glazing showed lower DGI and DGP when compared with the base case. However, a better luminance ratio (closer to 1) was collected from Alt1 and Alt2, which indicates better contrast as shown in the comparison results in Figure 8.



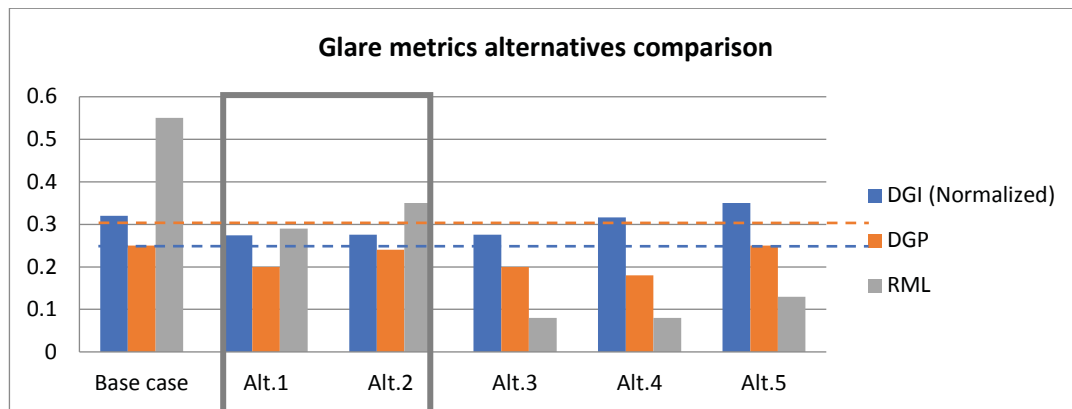


Figure 8: Glare metrics comparison between alternatives

## Final Conclusion

From the case study findings, it was confirmed that the argument succeeded in its intended goal to find adequate glare and visual comfort evaluation metrics. This can positively affect design decision-making, and improve upon existing design practices.

The paper findings show an in-depth understanding of glare and visual discomfort phenomena; it provided an approach describing in explicit detail the dynamics of space-making. The research concluded arguments regarding glare and visual comfort phenomena that are supported with a case study. The paper represents a contribution to prospective theory by developing and demonstrating an improvement in the design decision-making process.

## References

- Barbrow, I. 1964. International lighting vocabulary. *Journal of the smpte*, 73, 331-332.
- Bellia, I., Iuliano, G. & Spada, G. 2011. A comparison between dgi obtained through different methods and perceived evaluation index ddg.
- Budde, R., Kautz, K., Kuhlenskamp, K. & Züllighoven, H. 1992. Prototyping. *Prototyping*. Springer.
- Carlucci, S., Causone, F., De Rosa, F. & Pagliano, I. 2015. A review of indices for assessing visual comfort with a view to their use in optimization processes to support building integrated design. *Renewable and sustainable energy reviews*, 47, 1016-1033.
- Jakubiec, J. A. & Reinhart, C. 2011. The 'adaptive zone' – a concept for assessing glare throughout daylight spaces. *Building simulation 2011 sydney, australia*.
- Kleindienst, S. & Andersen, M. The adaptation of daylight glare probability to dynamic metrics in a computational setting. *Proceedings of the lux europa 2009 conference*. Lausanne, september 9e11, 2009.
- Linney, A. S. 2008. Maximum luminances and luminance ratios and their impact on users' discomfort glare perception and productivity in daylight offices: testing the hypothesis: maximum luminance and ratio recommendations for visual comfort should be specific to the luminous conditions and by accounting for the impact of adaptation, the recommendations will be more accurate.
- Osterhaus, W. Recommended luminance ratios and their application in the design of daylighting systems for offices. *The modern practice of architectural science: from pedagogy to andragogy, proceedings of the 35th annual conference of the australia and new zealand architectural science association (anzasca)*, 2002. 01-04.
- Parpaire, K., Baker, N., Steemers, K. & Compagnon, R. 2002. The luminance differences index: a new indicator of user preferences in daylight spaces. *Lighting research and technology*, 34, 53-66.
- Pointer, M. R. 1986. Measuring colour rendering—a new approach. *Lighting research and technology*, 18, 175-184.
- Thornton, W. A. 1972. Color-discrimination index. *Josa*, 62, 191-194.



- Xu, h. 1984. Color rendering capacity of illumination. *Journal of the illuminating engineering society*, 13, 270-276.
- YIN, R. K. 2008. *Case study research: Design and methods*, SAGE Publications, Incorporated.

# Parallel Parametric Simulation for Optimizing Non-Conventional Solar Screens: An Approach for Balancing Daylight and Thermal Performance in Hot Arid Climates

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**Abstract:** Growing interest in digital design tools and generative systems in the architectural discourse, especially parametric systems and optimization algorithms, has the potential to be of greater value if capable of expanding their scope from form generation tools to a more ecological-conscious approach by coupling them with performance simulation tools within a collaborative methodology.

The work presented in this paper is a part of a comprehensive study aim to compare between parametric simulations and Genetic Algorithms as a tool to optimize and analysis the effect of non-conventional solar screens on daylight, thermal and energy performance for south façades. This paper focused on the parametric simulation study of a non-conventional solar screen driven by daylight and thermal performance. It integrated simulation tool with parametric design using DIVA, and Grasshopper respectively.

The simulations were conducted for a south-oriented office space's façade in Cairo, Egypt. The screen various parameters; sizes, rotation angles, scale ratios, and protrusion values were modelled parametrically and aligned to this façade. Daylight analysis was conducted using Daylight Dynamic Performance Metrics specifically; Spatial-Daylight-Autonomy ( $sDA_{300/50\%}$ ) and Annual-Sunlight-Exposure ( $ASE_{1000/250hr}$ ), that comply with both LEED v4 and the new IES approved method, and Daylight Availability. While thermal analysis based on a comparison approach of the thermal performance results to a specific base case. Moreover, the screen shading coefficient was calculated to overcome the current limitations of thermal simulations in sufficiently recognizing the complex geometries such as the proposed screen.

Finally, the simulations relied on parallel computing algorithm, which saved time by 8 times more than the default runs. Meanwhile, an algorithm inside Grasshopper was specially developed for this study to overcome current limitation of running parallel thermal runs. The paper presented a comprehensive analysis using an exhaustive search method for the effect of the screen parameters on daylight and thermal performance.

**Keywords:** Parametric design, Solar screen, Daylighting, Thermal Performance

## Introduction

Parametric generative systems have made a major shift in the design process from designing an 'object' to design the 'logic' of the object, considering parametric optimization approach as a generative-explorative tool (Leach 2009). Hence, expanding the parametric potentials to a more ecological-conscious approach by coupling them with performance simulation tools within a comprehensive collaborative methodology in the current architectural practice can contribute in solving the energy problem in Egypt.

On the other hand, building façade plays a significant role in architecture; it is not only a mean to express the design concepts but it is the main moderator between interior spaces and exterior environment. The increasing reliance of office buildings on air conditioning and artificial lighting systems indicates the failing role of the building facade to perform its function as a moderator. Attributing to this rising energy demand is the office building

facades. In hot arid climates like Egypt, the facade's configuration is responsible for up to 45% of the cooling loads (Hamza, Dudek et al. 2001, Hamza 2008). Consequently, balancing thermal and daylight performance in office buildings in order to reduce the total energy consumption while enhance occupant comfort in an environmentally sustainable manner, has become a vital issue.

### ***Parametric approach potentials for performative design exploration***

Parametric tools in architecture have been gaining momentum over the past few years as it provides architects with the possibility of making modifications on any parameters without recreating the entire model (Wagdy, 2013). In this context, parametric modelling has the potential to address performative aspects in architecture by allowing the exploration of wide search space within specific performance metrics. This could be done by combining external simulation tools with parametric model in a comprehensive cycle till reaching the optimal solutions (G.Hassan 2016).

In a recent study (Wagdy and Fathy 2015) a comprehensive parametric approach was carried out for optimizing daylight performance using solar screens. The screen was tested using DIVA as a simulation tool and Grasshopper as a parametric tool. This study stepped away from conventional parametric methods by using parallel computing procedure, where multiple Radiance simulations conducted based on the available CPU, to find optimal solutions while solving the simulation running time problem. Similar studies focusing on the effectiveness of parametric simulation in exploring shading devices for daylight and/or thermal analysis could be found in (Naboni, Zhang et al. 2013, Sherif, Sabry et al. 2016).

In a more related work to this paper, studies by the author and others, conducted an exploration for an origami-based solar screen: kaleidocycle rings that can be morphed to balance daylight and thermal performance, which complies with both LEED V4 and Daylight availability. Results demonstrate that the optimal Kaleidocycle rings configurations weren't reached until the parametric optimization phase (Elghazi, Wagdy et al. 2014, Wagdy, Elghazi et al. 2015). Another important study addressed the limitation of simulating complex geometric screens in energy simulation software such as EnergyPlus (Omidfar 2011). As directly creating a complex surface geometry is infeasible using current simulation tools. This paper suggested that specific performance criteria including screen shading coefficient and a yearly electric lighting schedule based on daylight performance metrics had to be measured using DIVA. Similar studies that addressed non-conventional shading devices using parametric optimization for optimal performance could be found in (Turrin, von Buelow et al. 2011, Hegazy and Wagdy 2016)

### ***Parametric modelling tools***

In recent years, the design professions have begun experimenting with parametric design tools such as Grasshopper (GH). GH was developed by David Rutten at Robert McNeel & Associates in 2007 as a parametric modelling plug-in for Rhinoceros 3D modeling software (McNeel 2010). GH is graphical-base tool which doesn't require scripting knowledge to use it and thus, it is the most preferable parametric tools for architects. GH also has the ability to include many other plugins, such as environmental simulations plugins, to expand the parametric model ability to include performance aspects.

### ***Parametric Performance simulation tool***

Many current tools have the ability to allow a 'live' parametrically controlled digital model to be connected with a simulation program. There have been various plugins developed for

GH that connect the Rhino geometry to simulation software. DIVA-for-GH is used to interface DAYSIM/Radiance and EnergyPlus engines to measure daylight and thermal performance respectively. Using DIVA, daylight and thermal simulations could be carried out within Rhino and Grasshopper environment without the need to export the model to various simulation tools (Jakubiec and Reinhart 2011, Reinhart and Wienold 2011).

## Objectives

The work presented here is a part of a comprehensive study that aims to compare between parametric simulations approach and Genetic Algorithms as a tool to optimize and understand non-conventional solar screens effect on daylight, thermal and energy performance. However, this paper focused in the parametric part where parallel parametric simulations introduced to balance daylighting and thermal performance within the most energy efficient cases by optimizing multiple screen parameters.

## Methodology

The methodology implemented here is divided into two consecutive stages. Firstly, parallel parametric simulation was conducted for different screen parameters to study their effect on daylight performance. Secondly, thermal and energy performance was simulated for each configuration. The realization of various screen parameters required the geometry to be constructed in Grasshopper to control each variable parametrically. DIVA-for-GH was used for daylight and thermal simulations. The simulation results were then analysed using an exhaustive search method. Finally, the optimal solutions were identified.

### Base Case Parameters

The case study chosen to be located in Cairo, Egypt (30°6'N, 31°24'E, alt. 75m) which belongs to a subtropical desert arid hot climate according to Köppen's climate classification (Peel, Finlayson et al. 2007). Cairo is characterized by high direct solar radiation and clear sky that demands special façade treatments to minimize solar heat gain while providing appropriate daylighting. A south-oriented side-lit space has been defined as a hypothetical office space of 24 m<sup>2</sup> area. It is assumed that the space is bordered on five sides by similar spaces with no external obstruction and located at a mid-floor (Figure 1). The external façade has a window of 90% Window-to-Wall Ratio (WWR) as most of the curtain walls applied to the office buildings in Cairo. The proposed screen will be applied to this façade.

The office space is considered to be occupied daily from 8AM to 6PM which agree with IES approved method (IES 2012). The thermal properties were assigned according to ASHRAE90.1-2007 which complies with the Egyptian codes. Optical and thermal properties of all building components are listed in Table 1.

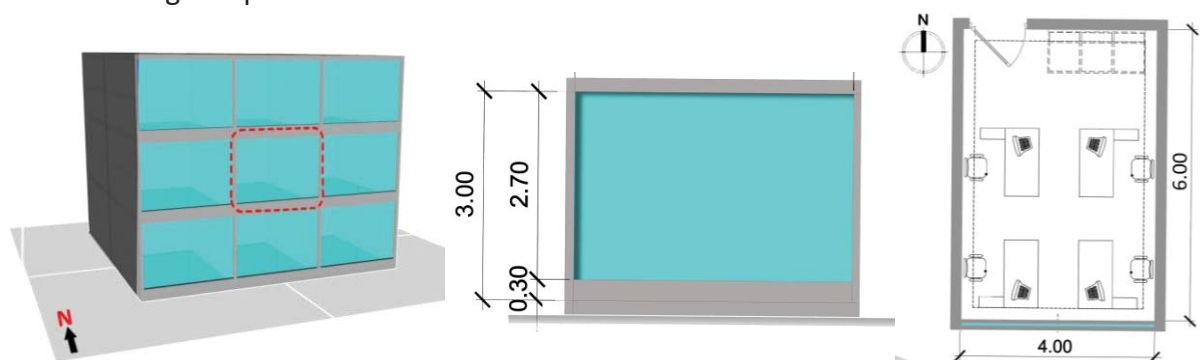


Figure 1: Base case 3D model showing its dimensions and location in the building.

Table 1 : Base case's parameters

Office room Parameters			
Office room Usage pattern		Thermal properties	
Occupant Load	0.17 occupant/m <sup>2</sup>	External wall U-Value	0.26 W/m <sup>2</sup> K
Heating set point	22°C	Internal wall /Ceiling / Floor	Set to be adiabatic
Cooling set point	26°C	Optical properties and reflectance	
Infiltration rate	0.5 ac/h	Walls Reflectance	50%
Lighting Type & Load	(Recessed fluorescent luminaires) 11.74 W/m <sup>2</sup>	Ceiling Reflectance	80%
Equipment Load	4.0 W/m <sup>2</sup>	Floor Reflectance	20%
		Screen Reflectance	Metal diffuse
Window optical and thermal properties			
Glazing type & Visual Transmittance (VT)	Double pane clear 80%		
Window U-Value	2.61 W/m <sup>2</sup> K		
Window Solar Heat Gain Coefficient (SHGC)	0.60		

### Screen design logic and parameters

A parametric diagrid-base screen model was generated by series of commands; rotate, scale, protrusion and surfaces' filling where each cell has one module (Figure 2).

**Four variables; size, rotation angle, scale ratio and protrusion values**, were the main parameters of the proposed screen which were controlled with numeric sliders and gene pool components within GH. **Three screen module's sizes** were introduced; 120\*120 cm, 60\*60cm and 30\*30cm. Moreover, **Six different rotation angles** starting from 0° to 75° with increment of 15° were used. Additionally, **five scale ratios configurations** ranging from 20% to 80% of the main cell area with increment of 15% were defined. However, it is important to notice that the scale range of each cell varies depending on its rotation angle. As only screen module with 0° rotation angle has the possibility to be scaled to 80% of its main cell size while other screen module with larger rotation angles could only be scaled to 65%. Furthermore, **five protrusion values** ranging from 5, 15, 30, 45 and 60 cm were used where two sets, horizontal points and vertical points take the same extrude value (Table 2).

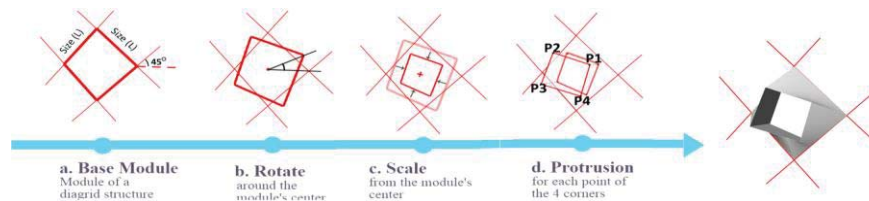


Figure 2: Main screen module form generation workflow.

Table 2: The screen parameters configuration (size, rotation, scale, protrusion)

Units' SIZE			Protrusion values			
120 cm	60 cm	30 cm	Different protrusion for Each point (5, 15, 30, 45, 60 cm)			
Rotation (0° to 75° with 15° increments)			Scale ratio (20%-80% with 15% increments)			
0°	15°	30°	45°	60°	75°	

### Methodology of stage one-Daylight Simulation

The aim of this stage is to investigate daylighting performance of the screen various configurations. Thus, a full detailed 3D model for the office space and the proposed screen were modelled and assigned with materials shown before in Table 1. The reference plane, on which daylighting performance was simulated, located at 80cm high above finish floor,

with 247 measuring points in a grid of 30x30 cm study. It represents an average of the different possible task heights and complies with IES's standard that consider 60x60 cm grid as the maximum reference plane grid size.

### Daylight Performance Metrics

The daylight simulation results were analysed based on Daylight Dynamic Performance Metritables (DDPMs); Daylight availability, spatial Daylight Autonomy ( $sDA_{300/50\%}$ ) and Annual Sunlight Exposure ( $ASE_{1000/250hr}$ ). ( $sDA_{300/50\%}$ ) and ( $ASE_{1000/250hr}$ ) comply with LEED V4 daylighting requirements and follow precisely the approved method by IES (IES 2012). For office spaces ( $sDA_{300/50\%}$ ) must be achieved for at least 55% to achieve 2 LEED credits or 75% to achieve 3 LEED credits while ( $ASE_{1000/250hr}$ ) must be less than 10% for both cases.

Daylight Availability (DA) was also evaluated as sDA combines both daylight and overlit area together. It has the same minimum threshold of the sDA, but it adds a maximum threshold that is ten times the minimum. DA divides the space into three zones: 'daylit', 'partially daylit' and 'over lit'. Measuring 'over lit' area was critical in this study as it signifies the potential for solar heat gain and also might signify a potential for glare.

### Daylight algorithm for parallel parametric simulations

The parametric algorithm followed specific procedures (Figure 3). First, the screen parameters took the same ranges and stepping values shown in Table 2 where all the screen modules take the same values as shown in Figure 3. Then, all these ranges were converted into two lists that contain all states of each parameter. The first list contains 1500 alternatives with rotation angles ranging from ( $15^\circ$  to  $75^\circ$ ) and thus scale ratio ranging from (20% to 65%) and the second list with 375 alternatives of rotation angles  $0^\circ$  with scale ratio from (20% to 80%) resulting in 1875 different screen configurations as a total. After that, all possible combinations of the screen parameters were computed and sorted in groups based on a cross reference algorithm inside Grasshopper (Figure 3).

Although this method was usually avoided due to its running time, this was overcome using parallel daylight simulations. The parallel algorithm was specifically designed for this type of research, where hundreds or thousands of simulations are needed to obtain precise evaluation of each parameter. Thus, the workflow is made to fully utilize the maximum count of available CPU cores. Based on that, the 1875 solutions were divided into 8 sub-lists each having about 235 solutions based on the available CPU cores of the used computer, which were 8 in this case. After that, parallel daylighting simulations using Diva Daylight for GH were automated to speed up the overall simulation by 8 times faster than the default runs resulting in a significant time savings by total duration of less than 5 days for all the 1875 cases instead of 40 days if using the default simulation runs.

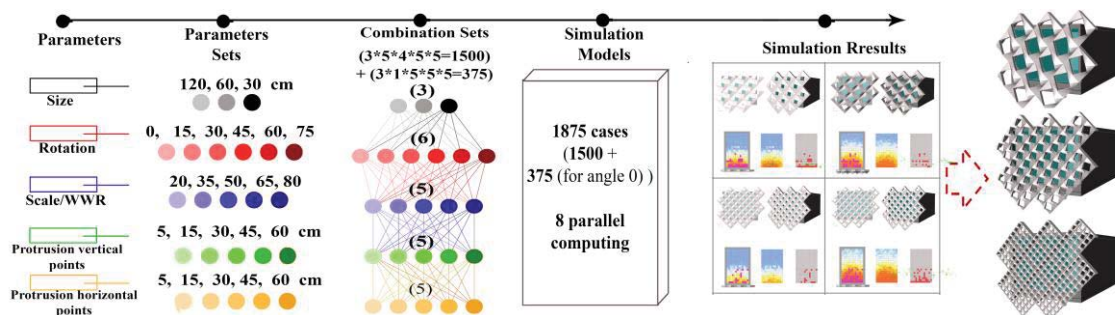


Figure 3: On the left: Parametric algorithms for computing all possible combinations. On the right: Some alternatives showing that for each solution, all screen modules had the same values.

Source: by the researcher based on (Wagdy and Fathy 2015)



### **Methodology of stage two- Thermal simulation**

The aim of this phase was to investigate thermal and energy performance of the office space with the various screen configurations using Viper-Diva for GH that interfaces with EnergyPlus. As thermal simulations including Energyplus have a limitation of dealing with single surfaces only, a single surface 3D model for the office space was modelled and connected to Viper to be simulated based on a TMY climate file, the occupancy type, and the thermal properties assigned to the construction elements that have been shown in Table 1. However, due to this limitation Energyplus can't sufficiently recognize the complex geometry of the screen to study its thermal behaviour. Thus, directly linking the screen complex geometry is still infeasible using current energy simulation tools. Hence, specific performance criteria of the screen had to be measured based on the output of DAYSIM/RADIANCE simulation results, which makes the energy calculation more accurate and sensitive for daylight results. These include the screen's shading coefficient and an annual electric lighting schedule based on sDA & DA results. The data were then synchronized with a thermal analysis performance using Viper-Diva for GH. The Energy simulation definition in Grasshopper is shown in Figure 4.

The calculation of the screen shading coefficient was based on the methodology presented in (Omidfar 2011) as discussed in the literature review. Thus, a grid of solar radiation sensors was placed vertically in the outside directly behind the screen to calculate the shading coefficient of each screen configuration to be connected to Viper for thermal analysis later. The shading coefficient was calculated through DIVA Daylight Analysis for GH by measuring the radiation penetration through the screen modules on the vertical test surface with and without the screen for every hour over the year (8760 hrs). The ratio of both values resulted in an hourly shading coefficient of the screen that was then connected to the transmittance schedule of the Shade component to be connected to Viper (Figure 4).

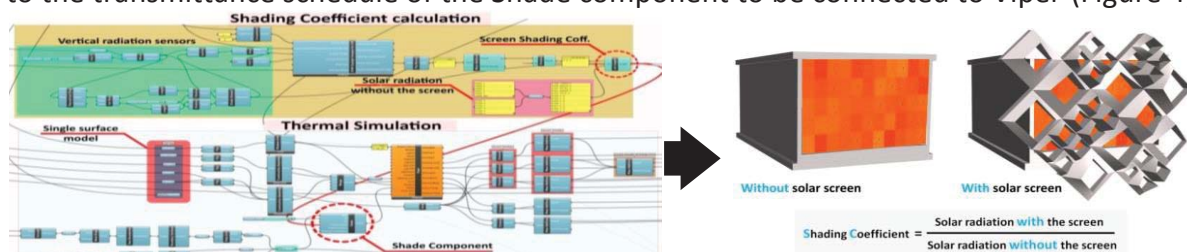


Figure 4: The Energy simulation script in Grasshopper that generated to measure screen's shading coefficient

Moreover, as there is no specific metric to evaluate thermal and energy performance, a comparison approach was followed between annual thermal and energy performance results of a base case and other tested instances. The performance of each alternative was calculated including cooling and heating loads as well as the annual energy consumption.

### **Thermal and energy algorithm for parallel simulations**

Unlike daylight simulation that could be run for more than one case at the same time, EnergyPlus could only be run for one case at a time. To overcome this limitation an original algorithm was specially developed for this study to achieve the maximum benefit of the parallel simulations for both daylight and thermal parametric simulations. Thus, a special algorithm inside GH was developed that recall annual electric lighting schedule file (**\*intgain.csv**) that had been generated and stored for each case during the parallel daylight simulations process to be connected to Viper component for thermal analysis. GH definition of this algorithm can be divided into 4 main steps. Firstly, the alternatives numbers' slider of

the parallel daylight simulation process was connected to the algorithm. Secondly, a series of commands were developed to generate the text of the lighting control schedule (\*intgain.csv) file destination name. Thirdly, the resulted file name was connected to “File path” component. Finally, the file path was connected to the lighting control input of the Viper thermal component (Figure 5). Then these steps were automated within GH to calculate all the 1875 cases thermal and energy performance. Thus, the methodology implemented here had the ability to automate thermal simulation runs for all the 1875 alternatives case-by-case after the completion of the parallel daylight simulation runs.

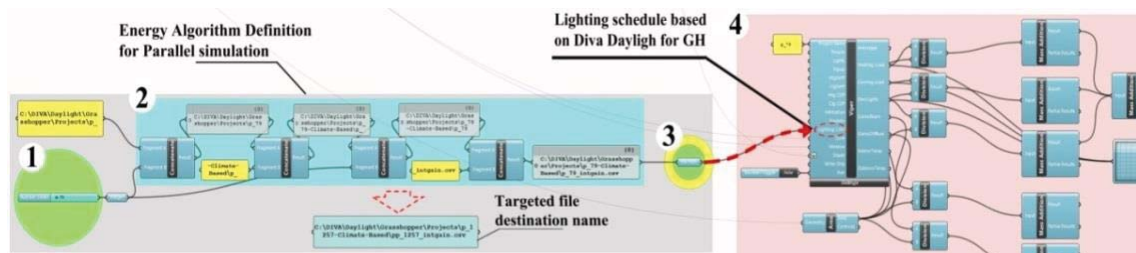


Figure 5: The Grasshopper definition of the thermal algorithm for parallel situations

## Parametric Simulation results and discussion

### Base case simulation results

A base case of the hypothetical office space without the screen was simulated for its daylight and thermal performance and the results are shown in Figure 6. For daylighting performance, the base case showed 100% of sDA and 0% partially lit area, but the over-lit area reached 67% and ASE reached 40%. For the thermal simulation, the extra amount of daylighting resulted in low electric lights loads by reaching 1.39 kWh/m<sup>2</sup> but on the other hand it allowed for extra amount of solar heat gains inside the space that raised cooling loads to be 285.56 kWh/m<sup>2</sup> while the heating loads was only 9 kWh/m<sup>2</sup> due to the dominant heat arid weather of Cairo and thus raised the total energy consumption consequently to reach 295.95 kWh/m<sup>2</sup>. It is clearly obvious that a window without any improvements specially when accompanied by large WWRs can barely achieve an adequate amount of daylighting and hence extra solar heat gain and thermal loads.

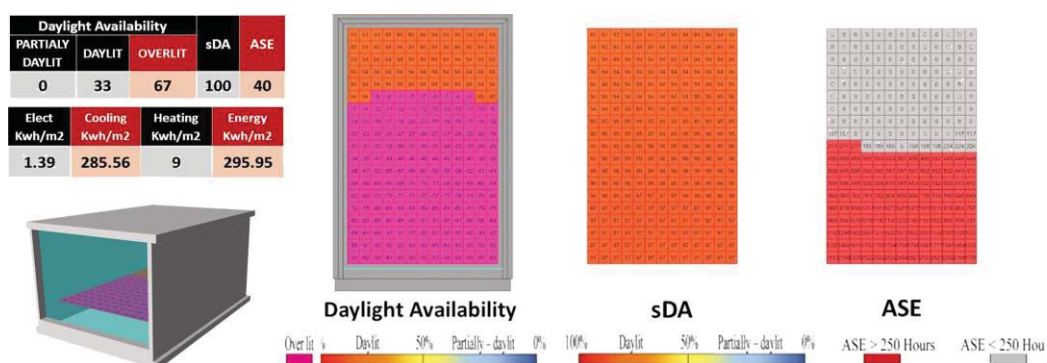


Figure 6: Base case simulation results

### Results and discussion of parametric simulation runs

Mostly, studying each parameter on its own, while fixing the others, doesn't give an accurate image about the overall performance. Thus, the interactions of all screen variables were explored using an exhaustive search method. Thus, the general tendency of each parameter and the impact of the interaction between them on the overall daylighting, thermal and energy performance were explored.

## Results of Daylighting simulation analysis

Firstly, different rotation angles' effect on the screen performance was investigated by comparing the minimum ( $0^\circ$ ), ( $30^\circ$ ) and the maximum ( $75^\circ$ ) for each size separately. According to the (120cm) size line graphs in Figure 7, almost no difference in sDA and ASE can be detected due to different rotation angles as shown by comparing cell(d),(e) and (f) in Figure 7. The same conclusion could be detected for the other two sizes, 60cm and 30cm, shown in Figure 8 and Figure 9 respectively. Generally, rotation angle have no relevant effect on daylight performance. However, using  $0^\circ$  rotation angle is recommended, as it gave better daylight performance due to its ability to have larger scale ratios than others.

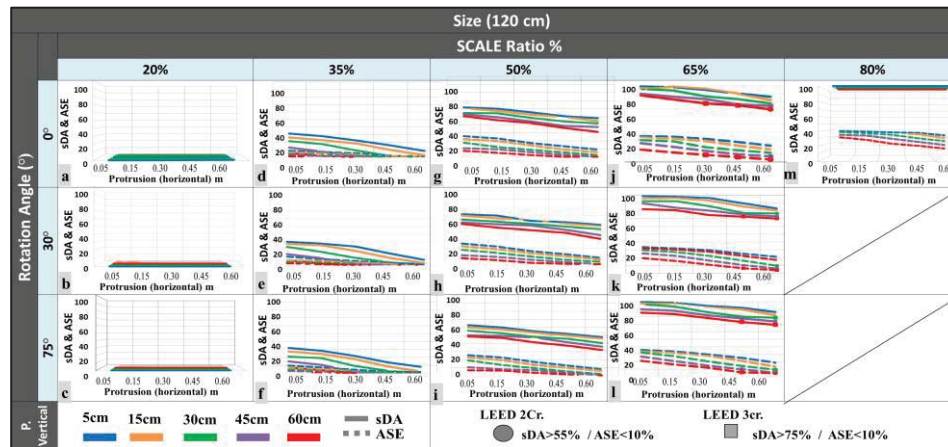


Figure 7: Comparing rotation angles, scale ratios and protrusion values for units size = 120cm

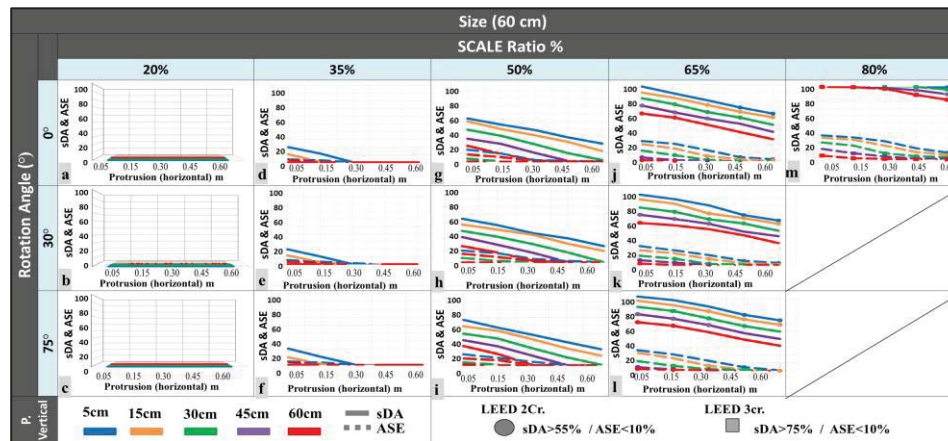


Figure 8: Comparing rotation angles, scale ratios and protrusion for units size = 60cm

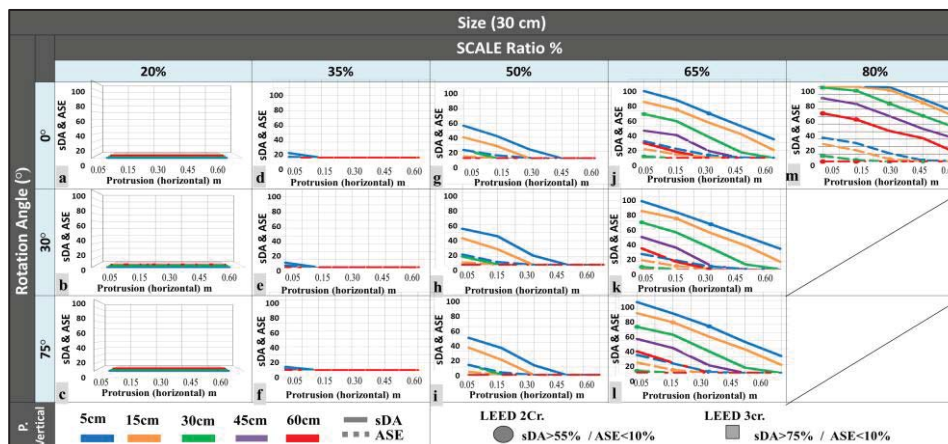


Figure 9: Comparing rotation angles, scale ratios and protrusion values for units size = 30cm



Secondly, to analysis the other screen parameters effect on the daylight performance, all 375 cases with 0° rotation angle were analysed in Figure 10 . The screen module sizes effect was investigated by comparing the three sizes; 120, 60, 30 cm where differences in sDA can be obviously detected starting from 50% scale ratios (Figure 10). For example, at 50% WWR with 15cm vertical and horizontal protrusion points, sDA decreased from 57% to 40% then to 18% by decreasing sizes from 120cm to 60cm and then to 30cm respectively as shown in cell(j), (h) and (i) in Figure 10. Conversely, this effect was unnoticed at small scale ratios due to nominal sun penetration. For 20% scale ratio, sDA showed a plateau of 0% for all sizes as shown in cell (a), (b) and (c) in Figure 10. The opposite case was noticed at large scale ratios, as sDA started to reach 100% plateau for all sizes. This was especially the case at 80% scale ratio with protrusion values from 5cm to 30cm, as a result of excessive sun penetration at small protrusion values as shown in cell(m), (n) and (o) in Figure 10.

Moreover, a sloped fall in sDA was noticed as screen module sizes decreased, yet the effect became sharper with large protrusion values. For 45cm vertical protrusion, screen size 120cm showed no difference in sDA values while 60cm and 30cm screen sizes experienced a significant decrease in sDA by 20% and 55% respectively as illustrated in cell(m), (n) and (o) in Figure 10 respectively.

Similarly, screen sizes parameter had a major impact on ASE performance. According to the graphs in Figure 10, differences in ASE can be detected starting from 50% scale ratio. For example, at 65% scale ratio with 15cm protrusion values for both horizontal and vertical points ASE decreased from 30% to 8% and then to 2% by decreasing the module sizes from 120cm to 60cm and 30cm respectively as shown in cell(j), (k) and (l) in Figure 10. Adding the contribution of protrusion values, differences in ASE values are distinctly influenced by different protrusion values for each size separately. On the other hand, the lowest ASE values could also be reached for smaller vertical protrusions when combined with larger horizontal protrusion value. For example, vertical protrusion values of 5cm, 15cm and 30cm reached the lowest ASE values when combined with 45cm, 30cm and 15 m horizontal protrusion values respectively as illustrated in cell (k) in Figure 10. Finally, the cases with 120cm screen module size barely reached the lowest ASE.

In conclusion, the integrated effect of screen module size and protrusion values had a remarkable outcome in converging solutions at large scale ratios where the accepted daylighting performance can be reached. In Figure 10, solutions which obtained 2 LEED credits can be found in cases with 65% scale ratios as shown in cell (k) in Figure 10. While optimum solutions that obtained with 3 LEED credits can be found in cases with 80% scale ratios for both 60cm and 30cm module size as illustrated in cell (n) and (o) in Figure 10.

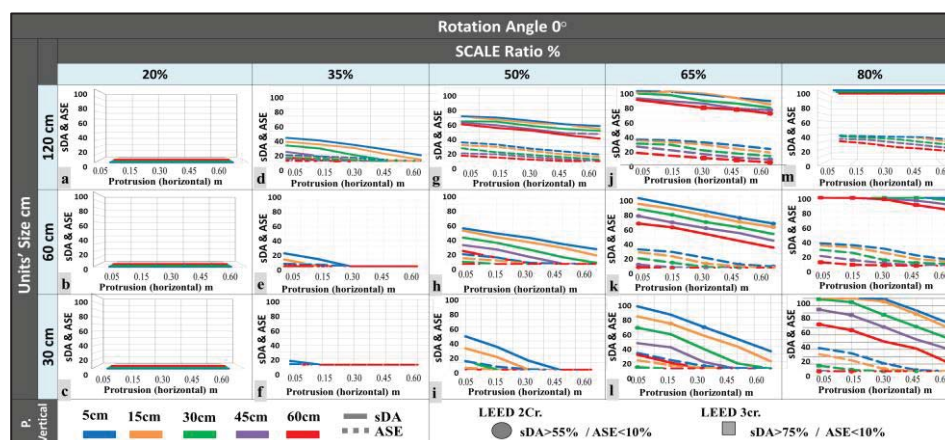


Figure 10: Comparing units' sizes, scale ratios and protrusion values (vertical & horizontal) for rotation angle=0

## Results of thermal simulation analysis

This section aims to analysis the thermal results of the parametric simulation and their correlations to the daylight performance so as to find the optimal balance between daylight and thermal performance with the maximum possible energy savings for each size. Thus, the best optimum alternatives for each size from the previous daylighting analysis and their corresponding thermal loads were explored in Table 3 below. Energy savings percentages were calculated compared to the bases case energy load, 295.95kWh/m<sup>2</sup> (Figure 6).

Regarding heating loads, they were almost constant at a certain level for each size ranged from 8.9 to 10.8 kWh/m<sup>2</sup> for cases with 30cm units' sizes, from 9.3 to 11.2 kWh/m<sup>2</sup> for cases with 60cm units' sizes and from 11.4 to 11.5 kWh/m<sup>2</sup> for cases with 120cm units' sizes. In contrast, cooling loads were the most influential in such hot arid climate. Thus, the optimum alternatives for each size were ordered ascending according to their cooling loads.

Table 3: 120cm, 60 cm and 30 cm units' size optimum alternatives thermal and energy performance

No.	Screen Parameters						Energy consumption			
	Size cm	Rotation angle	Scale ratio %	Vertical Extrude (cm)	Horizontal Extrude (cm)	Lighting Load (kWh/m <sup>2</sup> )	Cooling Load (kWh/m <sup>2</sup> )	Heating Load (kWh/m <sup>2</sup> )	Energy saving %	
1	120	0	65	60	60	8.02	115.61	11.49	54.4	
2	120	0	65	60	45	6.49	117.21	11.48	54.4	
3	120	0	65	45	60	8.03	118.89	11.39	53.3	

No.	Screen Parameters						Energy consumption			
	Size cm	Rotation angle	Scale ratio %	Vertical Extrude (cm)	Horizontal Extrude (cm)	Lighting Load (kWh/m <sup>2</sup> )	Cooling Load (kWh/m <sup>2</sup> )	Heating Load (kWh/m <sup>2</sup> )	Energy saving %	
1	60	0	80	60	45	4.78	134.73	11.17	49.1	
2	60	0	80	45	60	5.00	134.85	11.07	49.0	
3	60	0	80	60	30	4.86	135.18	11.09	48.9	
4	60	0	80	45	45	4.09	135.27	11.16	49.1	
5	60	0	80	60	15	3.41	135.81	11.00	49.2	
6	60	0	80	60	5	3.54	136.90	10.95	48.9	
7	60	0	80	45	30	4.07	137.39	10.99	48.5	
8	60	0	80	30	60	4.19	137.57	11.13	48.3	
9	60	0	80	30	45	3.02	138.41	11.07	48.5	
10	60	0	80	15	60	4.26	139.07	11.03	47.9	

No.	Screen Parameters						Energy consumption			
	Size cm	Rotation angle	Scale ratio %	Vertical Extrude (cm)	Horizontal Extrude (cm)	Lighting Load (kWh/m <sup>2</sup> )	Cooling Load (kWh/m <sup>2</sup> )	Heating Load (kWh/m <sup>2</sup> )	Energy saving %	
1	30	0	80	45	15	4.96	156.09	10.82	41.93	
2	30	0	80	30	30	5.49	156.58	10.83	41.59	
3	30	0	80	30	15	4.04	156.76	10.81	42.02	
4	30	0	80	45	5	5.43	157.03	10.79	41.47	
5	30	0	80	30	45	7.18	157.77	8.97	41.24	
6	30	0	80	60	5	7.39	158.00	10.73	40.50	
7	30	0	80	60	15	7.45	158.03	8.94	41.07	
8	30	0	80	15	45	6.69	158.66	10.78	40.50	
9	30	0	80	45	30	8.14	158.69	8.96	40.61	
10	30	0	80	15	60	8.16	159.21	10.76	39.82	

### Parametric simulation optimal cases

The optimal cases for each screen units' size, 120cm, 60cm and 30cm that could balance daylight and thermal performance with maximum possible energy savings was highlighted with the red dashed boundaries shown in Figure 11.

**For 120cm screen units' size**, the configuration of 0° rotation angle, 65% scale ratio, 60cm vertical protrusion and 45cm horizontal protrusion was the optimal case. It achieved 75% sDA with 6.5% ASE that couldn't comply with IES but comply with 3 LEED credits criteria, as well as achieving 22.5%, 58.3%, and 16.2% for partially daylit, daylit, and overlit areas respectively. These were accompanied with 117.21kWh/m<sup>2</sup>, 11.48kWh/m<sup>2</sup>, and 6.49 kWh/m<sup>2</sup> cooling, heating and electric lighting loads respectively. Resulting in 54% energy savings compared to the base case as illustrated in Figure 11.

**While for 60cm screens units' size**, the configuration of 0° rotation angle, 80% scale ratio, 60cm vertical protrusion and 15cm horizontal protrusion had proven its superiority in balancing daylighting and thermal performance. It achieved 99.6% sDA with 1.6% ASE that comply with both IES and 3 LEED credits criteria, as well as achieving 0.4%, 80.2%, and 19.4% for partially daylit, daylit, and overlit areas respectively. These were accompanied with 135.81 kWh/m<sup>2</sup>, 11 kWh/m<sup>2</sup> and 3.41 kWh/m<sup>2</sup> cooling, heating and electric lighting loads respectively. Resulting in 49% energy savings compared to the base case (Figure 11).

Finally, for 30cm screens units' size, the configuration of 0° rotation angle, 80% scale ratio, 30cm vertical protrusion and 15cm horizontal protrusion was the optimal case. It achieved 95% sDA with 2% ASE that comply with both IES and 3 LEED credits criteria, as well as achieving 5.3%, 80.6%, and 14.2% for partially daylight, daylight, and overlit areas respectively. These were accompanied with 156.76 kWh/m<sup>2</sup>, 10.81 kWh/m<sup>2</sup>, and 4.0481 kWh/m<sup>2</sup> cooling, heating and electric lighting loads respectively. Resulting in 42% energy savings compared to the base case as illustrated in Figure 11.

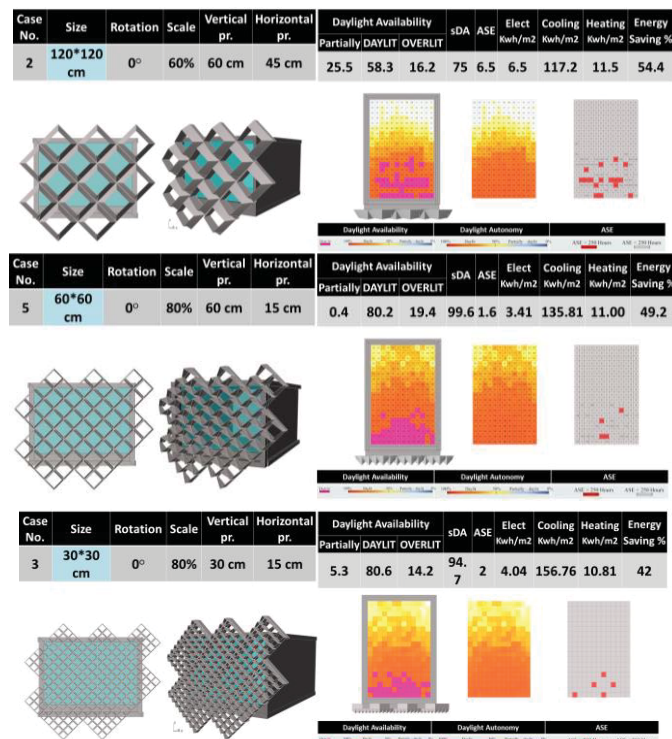


Figure 11: The optimal configurations for the 120 cm, 60cm and 30cm screens' sizes

## Conclusion

This paper presented a simulation-based study for non-conventional solar screens driven by daylight and thermal performance based on the integration of performance simulation tool with parallel parametric design algorithms using DIVA and Grasshopper (GH) respectively.

The simulations were conducted for south-oriented office space façade in Cairo, Egypt. Various screen parameters; size, rotation angle, scale ratio, and protrusion value, were modelled parametrically and aligned to this façade. Daylight analysis was conducted using Daylight Dynamic Performance Metrics (DDPMs) specifically; Daylight Availability, Spatial Daylight Autonomy (sDA<sub>300/50%</sub>) and Annual Sunlight Exposure (ASE<sub>1000/250hr</sub>), the last two are complied with both LEED-v4 and IES approved method. While thermal analysis relied on a comparison approach to a specific base case.

Parallel computing algorithm was adopted that automates parametric simulations for specific screen parameters resulting in 1875 alternatives. Parallel Radiance simulations saved time by 8 times more than the default parametric runs, by making the maximum benefits of the available CPU cores. In addition, an algorithm inside GH was developed specially to overcome current EnergyPlus limitation of running parallel thermal simulation. Thus, all the 1875 alternatives thermal simulations were automated after the completion of the parallel daylight simulations. The parametric simulations results were analyzed systematically using an exhaustive search method through two phases; first dealt with



daylight simulation analysis while the other concerned with the thermal and energy analysis. Finally, the optimal configurations for each screen's size were defined.

**For screens of 30 cm units' size**, 0° rotation angle, 80% scale ratio, 30cm vertical protrusion and 15cm horizontal protrusion was the optimal case. It complied with both IES and LEED v4 3-credits and accompanied with 42% energy savings compared to base case. **While for 60 cm units' size screens**, 0° rotation angle, 80% scale ratio, 60cm vertical protrusion and 15cm horizontal protrusion was the optimal case. It complied with both IES and LEED v4 3-credits and resulted in 49% energy savings compared to base case. **Finally, for 120 cm units' size screens**, 0° rotation angle, 65% scale ratio, 60cm vertical protrusion and 45cm horizontal protrusion was the optimal case. It couldn't comply with IES but complied with LEED v4 3-credits and achieved 54% energy savings compared to base case.

## Reference

- Elghazi, Y., A. Wagdy, S. Mohamed and A. Hassan (2014). Daylighting driven design: optimizing kaleidocycle facade for hot arid climate. Fifth German-Austrian IBPSA Conference Aachen, Germany, IBPSA: 314-321.
- G.Hassan, A. (2016). Parametric Design Optimization for Solar Screens: an Approach for Balancing Thermal and Daylight Performance for Office Buildings in Egypt. Master of science in Architectural Engineering, Cairo University.
- Hamza, N. (2008). "Double versus single skin facades in hot arid areas." Energy and Buildings **40**(3): 240-248.
- Hamza, N., S. Dudek and H. Elkadi (2001). Impacts of changing facade configurations on office building energy consumption in hot arid climates. Proceedings of the 7th REHVA World Congress and Clima 2000 Naples 2001 Conference.
- Hegazy, M. A. and A. Wagdy (2016). (submitted) Multivariable optimization for zero over-lit shading devices in hot climate. Building Simulation and Optimization BSO16. Newcastle, England, IBPSA-England.
- IES, I. E. S. (2012). "Standard LM-83-12. Approved Method: IES Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE)." Illuminating Engineering Society of North America, New York, USA.
- Jakubiec, J. A. and C. F. Reinhart (2011). DIVA 2.0: Integrating daylight and thermal simulations using Rhinoceros 3D, Daysim and EnergyPlus. 12th Conference of International Building Performance Simulation Association, Sydney.
- Leach, N. (2009). "Digital morphogenesis." Architectural Design **79**(1): 32-37.
- McNeel, R. (2010). "Grasshopper generative modeling for Rhino." Computer software (2011b), <http://www.grasshopper3d.com>.
- Naboni, E., Y. Zhang, A. Maccarini, E. Hirsch and D. Lezzi (2013). Extending the use of parametric simulation in practice through a cloud based online service. Proceedings of 1st IBPSA-Italy Conference: BSA2013–Building Simulation Applications Conference.
- Omidfar, A. (2011). A methodology for designing contemporary high performance shading screen- The integration of 'form' and the DIVA simulation tool. Building Simulation Conference BS 2011. Sydney, Australia.
- Peel, M. C., B. L. Finlayson and T. A. McMahon (2007). "Updated world map of the Köppen-Geiger climate classification." Hydrology and Earth System Sciences Discussions **4**(2): 439-473.
- Reinhart, C. F. and J. Wienold (2011). "The daylighting dashboard—A simulation-based design analysis for daylight spaces." Building and environment **46**(2): 386-396.
- Sherif, A., H. Sabry, A. Wagdy, I. Mashaly and R. Arafa (2016). "Shaping the slats of hospital patient room window blinds for daylighting and external view under desert clear skies." Solar Energy **133**: 1-13.
- Turrin, M., P. von Buelow and R. Stouffs (2011). "Design explorations of performance driven geometry in architectural design using parametric modeling and genetic algorithms." Advanced Engineering Informatics **25**(4): 656-675.
- Wagdy, A., Y. Elghazi, S. Abdalwahab and A. Hassan (2015). The Balance between Daylighting and Thermal Performance Based on Exploiting the Kaleidocycle Typology in Hot Arid Climate of Aswan, Egypt. AEI 2015, 6th Biennial Professional Conference 2015, Milwaukee School of Engineering (MSOE), Milwaukee, Wisconsin, United States., AEI 2015.
- Wagdy, A. and F. Fathy (2015). "A parametric approach for achieving optimum daylighting performance through solar screens in desert climates." Journal of Building Engineering **3**: 155-170.

# A checklist for the assessment of energy performance of public schools in Cairo, Egypt

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**Abstract:** In developing countries education is a constant struggle on most fronts, from the development of curricula to the design of schools. In Giza, Egypt, the public education population is rising rapidly, and classrooms available for education are few. In 2014 the average classroom density was 57.3 pupils/class for primary education, 52.2 for preparatory education, and 50.2 for secondary education. The UNICEF Child Friendly Schools' manual strictly limits classroom density to 30 pupils/class. Classroom occupancy affects the school energy performance; occupancy levels in Egypt are often below 0.8m<sup>2</sup>/person; this compares poorly with the range deemed acceptable in the UK (1.8 to 2.4m<sup>2</sup>/person). There is need for change in approaches to the design, construction and operation of public schools. Currently the Egyptian Energy Efficiency Building Code does not include education buildings. This study investigates avenues towards developing a checklist to follow for public education buildings, with a focus on loads generated by occupants.

The study reviews the rating systems to emphasise the importance energy efficiency parameters in education buildings. The methodology is performance-based, utilising an Energy plus application. The experiments investigate the variables (orientation, window-to-wall ratio, U-value, SHGC, shading and occupancy) affecting the energy consumption of classrooms. The classroom samples are based on the supplementary classroom buildings provided by the Egyptian General Authority for Education Buildings. The results demonstrate the influence of classroom occupancy; they also establish the parameters for optimisation for thermal comfort, providing a checklist to follow for the design and build of public schools.

**Keywords:** Energy Efficiency, Education Buildings, Occupancy, Egypt

## Introduction

Annual data reviewed by the World Economic Forum in the Global Competitiveness Reports show that between 2009 and 2017 the quality of education in Egypt moved into the lowest quintile, where it has remained. In 2014 the Global Competitiveness Index (GCI) rank was 118 and the quality of education rank was 148 out of 148 countries. It is clear that education in Egypt is suffering grave deficits (Schwab, 2009; 2010; 2011; 2012; 2013; 2014; 2015; 2016).

A review of statistics published by the Egyptian Ministry of Education further illustrates this situation: a majority of schools in urban regions suffer from overcrowding due to the limited number of classrooms available. The most vulnerable stage is primary education. The Greater Cairo zone is critical, with Giza governorate suffering the most: average classroom density in public primary schools was 57.3 pupils per class in 2013 (Education, 2013).

## *The General Authority for Education Buildings*

Public school buildings in Egypt are regulated by the General Authority for Education Buildings (GAEB). Since the 1992 earthquake, a single building type has dominated the education landscape – the supplementary classroom building – used to accommodate the rise in pupil numbers. The distinguishing features are: white concrete frames infilled with rose brick. They have been erected in every governorate in the country. The obvious

reasoning is the cost-effectiveness of one design, one construction method and one site management method.

Since there is no energy efficiency code specifically for school design, and the Energy Efficiency Building Code (EEBC) is not enforced in Egypt, the GAEB is the only local reference. The only environmental aspect really researched in depth by GAEB is daylighting.

Since 2014 the government has been pushing policies towards a gradual reduction in subsidies, making the need for an energy-saving design even more necessary (Mehrem, 2014). Energy efficiency is not currently at the forefront on the policy-making level, but it can be assumed that retrofitting the designs according to the climatic zone can offer more comfortable options for pupils and teachers alike.

The GAEB's current management standards are poor; it suffers from a "limited knowledge about strategic asset management, no clear goals, no training, no real risk plan and a lack of data" (Abdelhamid et al. 2013). In a 2009 survey conducted in Minya on three prototypes designed and constructed by the GAEB, around 53% of occupants expressed discomfort due to the heat loads in the classrooms (Gado & Mady, 2009).

### ***Public schools in Egypt***

Most public-school buildings commissioned by the GAEB are single-loaded, which allows for daylight to penetrate; however, they are lacking in thermal comfort. The most prominent features of these buildings are the structures and materials: sand-brick walls and reinforced concrete column and beam structures. The fenestration is simple sliding aluminium section frames around the glass; the glazing type is single 6mm clear.

The classroom building has a distinct character; the flexibility of the design means little needs to be done in the way of detailing since it usually follows a simple format of multiplying according to necessity. This is very cost-effective - whereby a single design can spawn thousands of buildings. The typical design can be a single linear four-classroom per floor building, or an eight-classroom per floor L-shaped building, etc. In most of the cases it is four stories (Figure 1).



Figure 1 Typical layout of classroom buildings (photo: Al Tabarak Engineering & Contracting)

### ***Green schools***

A brief history of green schools can help develop an idea about the trends and developments in school design over the last century. One of the first green approaches towards school design was the Open-Air School Movement (Edwards, 2006). The 1934 Hadow Report on the Primary School, which highlighted the importance of sunshine and

ventilation on the health and performance of pupils. Early research on school buildings focused mainly on daylighting, and by the 1950s the daylighting factor was the prime tool used in classroom design regulation. At the turn of the century, environmental research in education buildings was revised to include other factors. The "Classrooms for the Future" initiative, introduced by Edwards in the UK in 2002, was a policy aimed at research and the production of guidelines for a new century.

Edwards also concludes that measuring the performance of green versus non-green schools through the analysis of the Standard Assessment Tests (SATs) showed that pupils in green schools had a higher average score than those in non-green schools (Edwards, 2006). Pupil absenteeism was also lower in green schools.

## Rating systems and norms

### *Climate*

Egypt is divided into 6 climatic regions, each having specific characteristics that result in unique demands (Figure 2). Each region has distinct environmental, cultural and economic features that influence the design process. Ignoring these features risks damaging the harmony between environment, culture and economy.

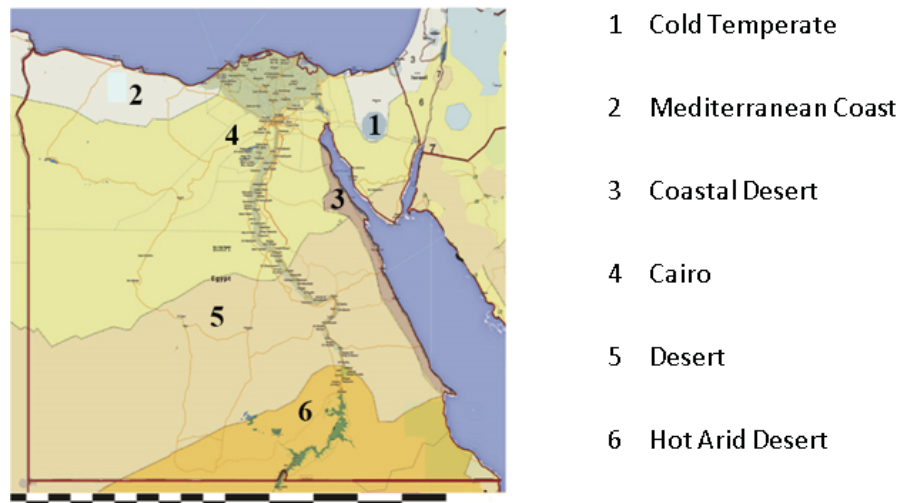


Figure 2 Climatic Map of Egypt

Each region has a distinct difference in climate (Figure 2). It is erroneous to assume that a school in Alexandria will perform according to the climate in the same way a school in Cairo or Asyut will. Differences in humidity, temperature and rainfall make that assumption invalid. Additionally, logistics, resources and materials differ according to region. The more remote the region, the less efficient it is to import materials from other regions.

The most densely populated cities are Cairo, Alexandria and Asyut. As it has 25% of the population, it is fitting to work on the analysis of Cairo since it will affect the greatest number of pupils and pose the highest risks.

### **LEED**

In the Leadership in Energy and Environmental Design (LEED) 2009 for Schools New Construction and Major Renovations Rating System, 2 points are reserved for thermal comfort, 2 points for heat island effect and a possible 4–19 points for optimized energy performance; this makes the possible weights for energy efficient design factors 20.91%. Primary factors are defined as air temperature, radiant temperature, air speed and humidity. To achieve these credits, a thermal comfort survey of building occupants must be conducted

within 6–18 months after occupancy. In addition to achieving points, the LEED for schools is only awarded after the inspection and implementation of pedagogical approaches towards environmental awareness.

### ***BREEAM***

The Building Research Establishment Environmental Assessment Methodology (BREEAM) is processed by awarding points for each criterion achieved; a set of environmental weightings is then applied to each of the criteria. Education buildings fall under the category of non-domestic buildings. Recommendations for schools vary according to stage and type. Thermal comfort and energy efficiency account for 31.5% of the points that need to be achieved.

### ***The Green Pyramid Rating System***

The Green Pyramid Rating System (GPRS) has been developed to fit the sustainability, with the intention of providing a benchmark tool for good practice specific for Egypt. The energy efficiency and indoor environmental quality sections together make up 35% of the requirements for achieving the rating. However, education buildings are not specifically identified.

### ***UNICEF***

In the UNICEF Child Friendly Schools Manual, energy efficiency and thermal comfort are addressed holistically. The scope of the manual is vast however it handles architectural issues loosely. Climate change is adopted, however thermal comfort and energy consumption are not discussed. It classifies the priorities for children and emphasises the need for planning education policies to deal with changes in pedagogical concepts (Wright, et al., 2009). The maximum ratio recommended is 30 pupils/teacher, i.e. per classroom.

## **Objectives**

The main goal of this study is to develop a checklist for the assessment of public-school buildings to achieve energy efficiency in the classroom. The objectives are:

- to develop a clear vision for the energy efficient design of public schools;
- to highlight the significance of the building envelope in school design;
- to illustrate the importance of human occupancy in the space.

## **Methods**

This study sets the optimisation of energy performance in Egyptian education buildings in the Greater Cairo area, and defines the required parameters. The parameters analysed were: insulation, window to wall ratio (WWR), glazing, shading and occupancy. The evaluation of energy efficiency is developed by calculating the energy savings as a result of the efficiency optimization of each parameter singularly, this is to ensure the independence of each variable. Finally, a checklist was deduced for the assessment of energy efficiency for public school buildings in the greater Cairo area.

## ***Experimentation***

This study makes certain provisions for a performance-based approach, namely the isolation and simulation of each variable independently to understand the limiting factors that need to be optimised.



## Tools

On reviewing the building energy simulation programs (BESP) analysis (Atieh, 2007), it was evident that the software most suitable for use in the analysis of the case in this study was DesignBuilder. This is due to its graphical flexibility as well as its citable record.

## Dimensions

The variables selected to focus on in this study are insulation, glazing, shading and student occupancy. Each simulation is tested against a base case simulation, the base case reflects the current situation. The sample design chosen for this study is the supplementary building model no. 91001a from the GAEB design archives. The building consists of four levels, ground floor and three more, the ground and first floors are usually reserved for administrative and laboratory spaces. The last two floors are solely reserved for classrooms (Figure 3).

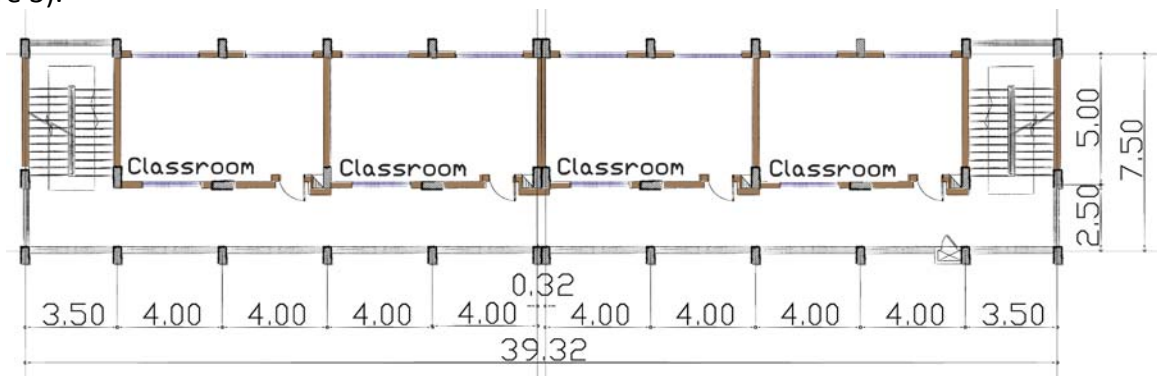


Figure 3 Plan of Supplementary Building Model No. 91001A, GAEB

Table 1 shows the dimensions of the base case. The current average occupancy level is 57.3 pupils/classroom; the average area per pupil is 0.713 m<sup>2</sup>.

Table 1 Building Dimensions

1. Classroom Dimensions			
Shape		Rectangular	
Volume		143.13m <sup>3</sup>	
Floor Area		40.89 m <sup>2</sup> (W 5.01m x L 8.16m x H 3.5m)	
External Wall Area		28.15 m m <sup>2</sup>	
Partition Area		17.54 m <sup>2</sup>	
Window Area		8 m <sup>2</sup> ((W 2.50m x H 1.6m) x 2)	
Window	Wall	Ratio	28.42% ≈ 30%
(WWR)			
2. Building Envelope			
Exterior Wall		Rose Brick 250mm Mortar 20mm	
Roof Materials		50mm Cement Tile & Mortar 50mm Sand 70mm Cement Mortar 50mm Expanded Polystyrene (Heavyweight) 200mm Reinforced Concrete (2% Steel) 20mm Gypsum Plastering	
Glazing		Single clear 6mm	
3. Thermal Properties			
		U-Value	R-Value
Exterior Wall		2.866 W/m <sup>2</sup> K	0.349 m <sup>2</sup> K/W
Roof		0.497 W/m <sup>2</sup> K	2.012 m <sup>2</sup> K/W
Glazing Frame		5.881 W/m <sup>2</sup> K	0.17 m <sup>2</sup> K/W
Glazing		6.121 W/m <sup>2</sup> K	0.16 m <sup>2</sup> K/W
		Solar heat gain coefficient	0.81
(SHGC)			



## **Process**

The base case is measured twice, once at WWR 10% and again at WWR 30%. In the case of WWR 10% loads due to glazing are negligible; this makes measuring and calculating loads due to walls simpler and more accurate. The more a variable is isolated the more accurate the result is. For loads due to glazing, WWR 30% is the actual ratio used in this model design and most newly built public schools follow this ratio.

Energy efficiency is determined by assuming that the space uses air-conditioning to achieve thermal comfort. Thus, in the base case the energy consumed (kWh) is the standard on which to measure. The energy consumption measurements on which the simulations depend are: total cooling (the main consideration), and wall, glazing and solar gains, all measured in kWh.

Orientation is important since the building is a modular design and is repeated as a supplementary building for most public schools. It is very difficult to predict the orientation of the hypothetical school, so simulation must cover all eight directions. This ensures further accuracy in the way of orientation.

The total cooling loads are taken to measure consumption. If the energy spent on maintaining thermal comfort in the room is considered as the unit, then the total cooling results would be the scale to measure against. It should be made clear that the values collected (kWh) assume that the space is air-conditioned and the consumption calculated is the result of maintaining comfort levels within the acceptable spectrum.

## ***Optimisation for Simulation***

The optimization of simulation involves a number of parameters; the constant parameters are:

- Orientation: Since the suggested building type is a modular based design that is set and designed beyond the constraints of the site layout, it is best to simulate according to the eight orientations (N, NE, E, SE, S, SW, W, NW)
- Window–Wall Ratio (WWR): When the Window–Wall Ratio (WWR) is 20% or above, glazing starts to become a dominant contributing factor to solar gain. The WWR for the chosen GAEB model is 30%, further simulation of WWR 40% and 50% for higher lighting performance.
- Wall Thermal Resistivity: According to energy code recommendations, WWR 10% is the standard for determining the required resistivity values of the walls and thus the target R-Value for building envelope performance.

These parameters represent the elements that affect the thermal performance of the building envelope: roof insulation, external walls insulation, window–wall ratio, type of glazing and shading device. It should be noted that all simulations are performed according to the above-mentioned eight orientations, WWR only changes for glazing simulations, the wall thermal resistivity is constant except for insulation simulations.

## ***Simulation settings***

In Cairo, the northern orientation performs better than other directions, and so it is important to note that north is the optimum case to aim for. For other orientations, the closer the performance is to the north the better.

In every case the set point temperature of the air-conditioning unit is 26°C for cooling for heating 19°C, the scheduled week works throughout the year and is set from Sunday to Thursday from 8:00 to 15:00 (Fridays and Saturdays are set as days off). All equipment and

machinery are set off, the simulation is set to measure the effect external loads have on the building envelope and so any loads within the building envelope are neglected. There are two reasons for this assumption: it is important not to confuse internal loads with external loads and it is assumed that the simulation model houses little in the way of equipment.

The base case is measured twice, once at WWR 10% and again at WWR 30%. In the case of WWR 10% loads due to glazing are negligible; this makes measuring and calculating loads due to walls simpler and more accurate. The more a variable is isolated the more accurate the result is. For loads due to glazing, WWR 30% is the actual ratio used in this model design and most newly built public schools follow this ratio.

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The base case simulation runs on four cases, this is to show accurate results (Table 2, Figures 4, 5).

Table 2 Surface Settings

Case	W1	W2	W3	W4	Floor	Roof
Typical Classroom	On	Adiabatic	On	Adiabatic	Adiabatic	Adiabatic
Typical Corner Classroom	On	On	On	Adiabatic	Adiabatic	Adiabatic
Typical Roof Classroom	On	Adiabatic	On	Adiabatic	Adiabatic	On
Typical Corner Roof Classroom	On	On	On	Adiabatic	Adiabatic	On

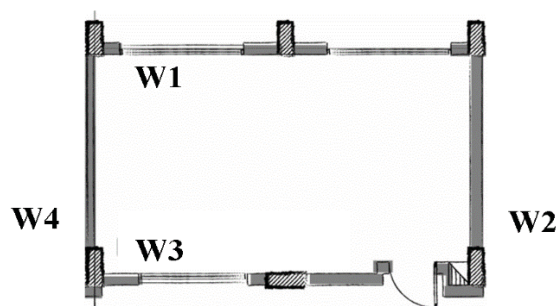


Figure 4 Key for Table 2

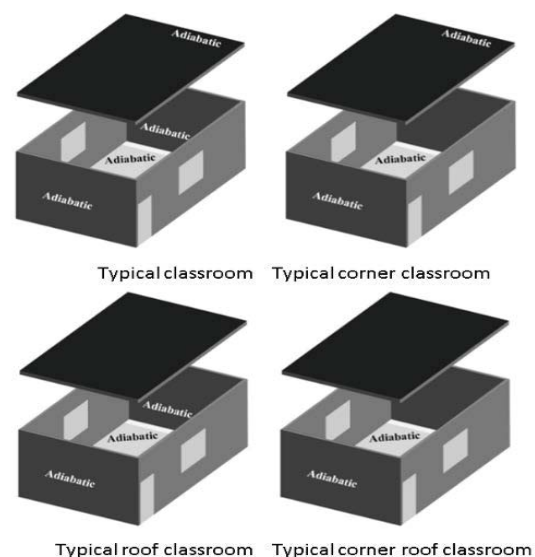


Figure 5 Illustration of the Cases in Table 2

## Results and discussion

### Initial optimisation

First the experimentation starts with the simulation of two cases on the typical classroom. The first case where the facade wall and the wall adjacent to the corridor are active and the second case where only the facade wall is active. It is clear from the results presented in Figure 6 that simulating on the facade wall alone is more accurate to confirm the results relating to that wall.

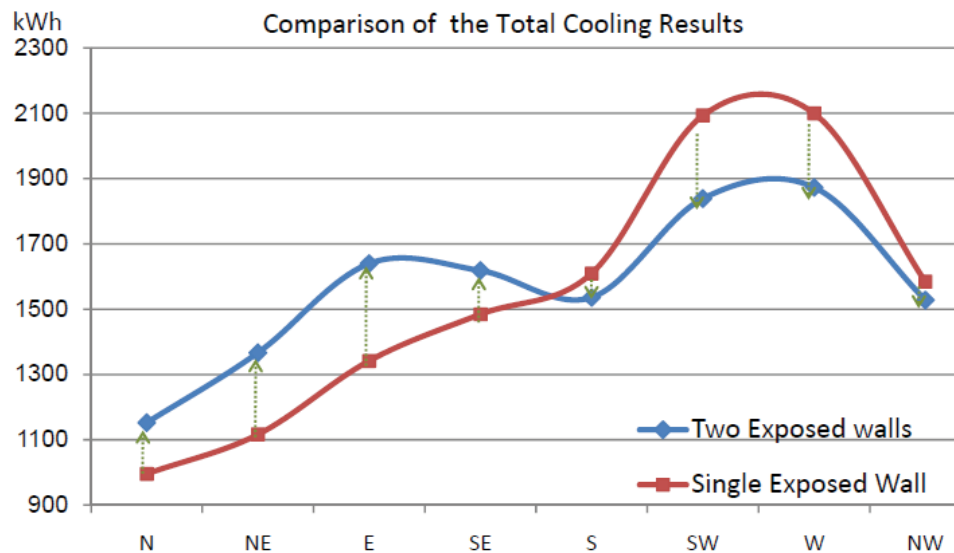


Figure 6 Comparative Results from Simulation Runs on One and Two Exposed Walls

Upon review the results of the initial simulation for optimisation, it was decided to turn the wall adjacent to the corridor (W3) from on to adiabatic, thus ensuring the results represent the effect of the external façade. Table 3 shows the amendments.

### Insulation

In order to reduce variables affecting the wall, it is necessary to factor out the WWR from calculations. This is achieved by considering WWR at 10%. After simulating the insulation base case, a series of simulation runs are applied with new wall sections, the variable part of these wall sections is insulating material, in these runs the material chosen is expanded polystyrene (EPS). The EPS layer is sandwiched between two masonry layers; the outside layer is 12 cm thick rose brick used to keep the visual identity of the building (Table 4 ). The inner layer is clay brick, also 12 cm, chosen for its thermal mass properties. The thickness of EPS ranges from 0cm to 10cm.

Table 3 Insulation simulation settings

Case	Base	1	2	3	4	5	6	7	8	9	10
Insulation (cm)	0	1	2	3	4	5	6	7	8	9	10
U-value	2.87	1.34	0.97	0.87	0.62	0.53	0.46	0.41	0.36	0.33	0.3

It is apparent that each orientation follows a logarithmic pattern. In analysing the results (Table 4), the logarithmic pattern ends at a point where an increase in the thickness of the insulating material EPS causes minimal change. Figure 7 illustrates a trendline for the average total cooling results. The optimum cut-off point was selected as 5cm EPS insulation; after that point the differences tend to converge towards a horizontal slope.

Table 4 Total cooling results for insulation (kWh)

Case	Base	1	2	3	4	5	6	7	8	9	10
North	973	871	829	801	780	765	754	745	737	731	726
North East	1063	940	894	863	841	824	811	801	793	787	781
East	1284	1120	1063	1025	997	977	961	949	939	931	924
South East	1397	1215	1153	1111	1081	1058	1041	1027	1016	1007	1000
South	1522	1330	1259	1211	1175	1149	1129	1113	1101	1090	1082
South West	2046	1813	1720	1657	1611	1578	1552	1532	1516	1502	1491
West	2087	1857	1764	1701	1655	1622	1597	1577	1561	1548	1536
North West	1556	1383	1313	1266	1232	1207	1188	1174	1162	1152	1143

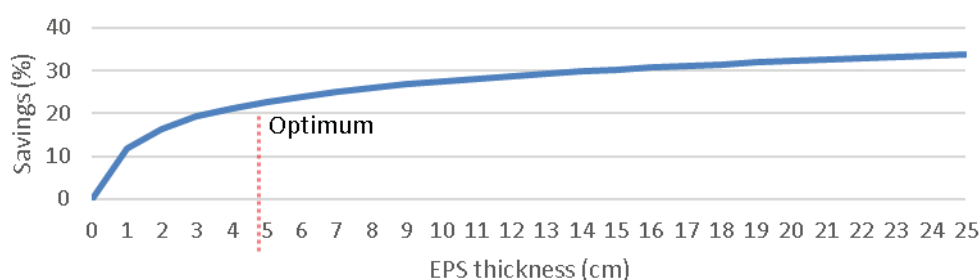


Figure 7 Average savings due to insulation

### Glazing

For the glazing simulations, a different base case was prepared; the typical classroom window wall ratio WWR is 30% and to test the thermal performance of the glazing material, it is important to lay out its performance at WWR 50%, and from there the strategy follows the simulation for glazing which was to simulate at three WWR 50%, 40% and 30%. The base case material is set as single clear-glass of thickness 6mm. The main two variables focused on are thermal transmittance (U-Value) and solar heat gain coefficient (SHGC), Table 6. The base case is set at WWR settings, 30%, 40% and 50%, this is to show the performance should there be a need to change to a higher WWR in the case of design modification.

Table 5 Simulation settings for glazing

Case	Base case	case 1	case 2	case 4
Type of glazing	Single Clear 6mm	Double Bronze 3mm 13mm air	Double Clear Refracted 6mm 13mm air	Double Clear 6mm 13mm air
U value	6.12	2.76	3.11	2.71
SHGC	0.81	0.62	0.42	0.7
VT	0.88	0.62	0.31	0.78

The vulnerable directions to place a window on are south west and west (Table 7). The amount saved on the south west at WWR 50% for double clear glazing 6mm with 13mm air gap is 94.3 kWh and for double clear refracted 6mm glass with 13mm air gap the saving is 1415 kWh. Figure 8 shows these results as percentage savings.

Table 6 Total cooling results for glazing (kWh)

WWR	Case	Base case	Case 1	Case 2	Case 4
30%	N	1372	1258	1062	1163
	NE	1537	1399	1172	1287
	E	1928	1733	1430	1580
	SE	2173	1930	1569	1746
	S	2453	2168	1722	1943
	SW	3347	2984	2349	2657
	W	3256	2961	2369	2657
	NW	2289	2085	1713	1891
40%	N	1559	1423	1932	1294
	NE	1763	1595	1289	1444
	E	2249	2007	1588	1794
	SE	2574	2264	1757	2008
	S	2973	2593	1945	2270
	SW	4013	3575	2675	3115
	W	3812	3477	2664	3064
	NW	2631	2398	1892	2136
50%	N	1601	1461	1182	1324
	NE	1814	1641	1315	1479
	E	2321	2071	1624	1844
	SE	2665	2344	1801	2068
	S	3094	2696	1998	2347
	SW	4165	3717	2750	3222
	W	3934	3598	2731	3157
	NW	2706	2471	1932	2191

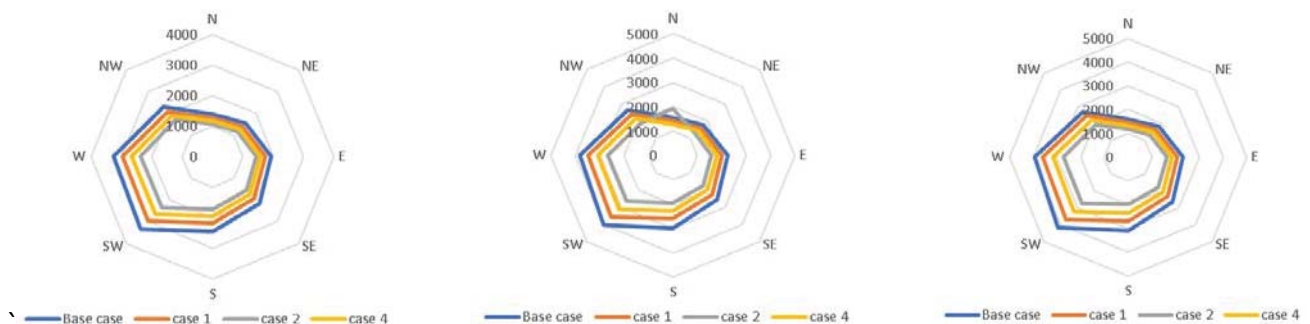


Figure 8 Total Cooling Savings (%) at WWR 30%, 40% and 50 %

### Shading

For shading calculations the base case was set for WWR 30% and the orientations were set at the most critical orientations on the building envelope were the east, south east, south, south west and west; other orientations are redundant in solar gain terms.

There are 4 simulation cases; the variable element is the projection of horizontal overhangs in which the change is set 0.0m, 0.5m, 1.0m, 1.5m and 2.0m.

Table 8 shows the settings for simulation of shading with base case set at 0.0m projection, giving a 0.0 projection factor. At projection factor 0.83 (= 2.0m) energy savings reached 50%.

Table 7 Simulation Settings for Shading

Case	Base case	Case 1	Case 3	Case 4	Case 5
Projection (m)	0	0.5	1	1.5	2
Projection Factor	0	0.21	0.42	0.63	0.83

Critical directions are south east to west (Tables 9, 10); other directions are omitted.

Table 8 Total cooling results for shading (kWh)

Case	Base case	Case 1	Case 3	Case 4	Case 5
East	1928	1576	1381	1286	1236
South East	2173	1650	1403	1309	1265
South	2453	1770	1476	1358	1313
South West	3347	2523	2037	1804	1686
West	3256	2663	2260	2024	1874

Table 9 Savings in energy consumption due to shading (%)

Case	Base case	Case 1	Case 3	Case 4	Case 5
Pf	0	0.313	0.625	0.94	1.25
East	0	18	28	33	36
South East	0	24	35	40	42
South	0	28	40	45	46
South West	0	25	39	46	50
West	0	18	31	38	42

### Occupancy

The simulation base case was set at WWR 30% with zero occupants. Occupancy was measured at intervals of 10 pupils; six intervals were simulated, 10–60 pupils per class (Table 10). From the results, it is clear that the occupants' metabolism results in an increase in discomfort. Energy consumption rates increase with number of pupils per class and compared with the base case, the increase is significant. The optimum occupancy is 30 pupils/class (Table 11).

Table 10 Occupancy Settings and Results

Pupils per Class	0	10	20	30	40	50	60
M <sup>2</sup> per pupil	0.00	4.0894	2.0447	1.363133	1.02235	0.81788	0.681567

Table 11 Total cooling results due to occupancy

Orientation	Pupils per Class						
	0	10	20	30	40	50	60
North	1372	1934	2558	3329	4131	5088	6086
North East	1537	2114	2749	3528	4335	5296	6470
East	1928	2562	3243	4072	4933	5945	7165
South East	2173	2883	3655	4615	5608	6707	8021
South	2454	3340	4284	5388	6455	7598	8943
South West	3347	4225	5160	6264	7341	8497	9835
West	3256	4016	4813	5785	6787	7903	9203
North West	2288	2929	3609	4430	5279	6277	7464

Due to the occupancy schedule - working day is 08:00 to 15:00 - consumption rates tend to be higher towards the south west. Table 12 shows the average increase in consumption.

Table 12 average consumption rate due to occupancy

Pupils per Class	10	20	30	40	50
Average increase in energy consumption %	30.77	63.83	103.82	144.45	190.44

### Conclusion

It is clear from the results that the simulations verified that the design can be improved through retrofitting materials (insulation and glazing) and elements (shading overhangs).

It was also demonstrated that the occupancy of a classroom adds to the level of consumption and that high occupancy rates do adversely affect the comfort of a space.



Indeed, high occupancy rates have an additional effect on the academic performance of pupils, as stated by Edwards, 2006.

There is a need to regulate school buildings in terms of thermal performance and occupancy. From the findings of this study, the checklist outlined in Table 13 is proposed as an aid towards securing energy efficiency in school building design.

Shading might be more economical and more effective than changing glazing. Solar radiation is more intense in the afternoon, around 2pm. Orientations with the highest risk due to solar gain, in order of severity, are south west, west, south, and south east.

Since the GAEB models are repetitive and do not adhere to restrictions in orientation, the most reliable way to formulate a checklist is to provide recommendations towards ensuring the best possible performance. Choice of materials and methods and occupant behaviours can inform the design process. The study proposes a checklist (Table 13) derived from the results, to be considered as a guideline for classroom construction in Cairo.

Table 13 Proposed Checklist for Achieving Energy Efficient Design

Design	Orientation							
Classroom Wall	North	North East	East	South East	South	South West	West	North west
Wall U-value	0.97	0.87	0.53	0.53	0.53	0.53	0.53	0.97
Glazing SHGC	0.81	0.81	0.42	0.42	0.42	0.42	0.42	0.81
Shading Pf	None	None	None	0.63	0.63	0.63	0.63	None
Occupancy	Design for a Minimum of 1.36m <sup>2</sup> /pupil							

## References

- Abdelhamid, M., Beshara, I. & Ghoneim, M., 2013. Asset Management for Educational Buildings in Egypt. *International Journal of Social, Management, Economics and Business Engineering*, 07(06), pp. 635 - 644.
- Education. 2013. *Pre-university education statistical summary 2013/2014*. Cairo: Ministry of Education.
- Edwards, B. W., 2006. Environmental design and educational performance: with particular reference to 'green' schools in Hampshire and Essex. *Research in Education*, 76(1), pp. 14-32.
- Gado, T. & Mady, M., 2009. *Assessment of thermal comfort inside primary governmental classrooms in hot-dry climates Part I a case study from Egypt*. Loughborough, SUE-MoT, p. 979–990.
- Gado, T. & Mady, M., 2009. *Assessment of thermal comfort inside primary governmental classrooms in hot-dry climates Part II a case study from Egypt*. Loughborough, SUE-MoT, p. 991–1001.
- Gordon, D. E., 2010. *Green Schools: Attributes for Health and Learning*. [Online].
- Mehrem, K. H., 2014. *Solving Egypt's Energy Subsidies Crisis*, Cairo: Egyptian Streets.
- Schwab, K., 2009. *Insight Report: The Global Competitiveness Report 2009–2010*, Geneva: World Economic Forum.
- Schwab, K., 2010. *Insight Report: The Global Competitiveness Report 2010–2011*, Geneva: World Economic Forum.
- Schwab, K., 2011. *Insight Report: The Global Competitiveness Report 2011–2012*, Geneva: World Economic Forum.
- Schwab, K., 2012. *Insight Report: The Global Competitiveness Report 2012–2013*, Geneva: World Economic Forum.
- Schwab, K., 2013. *Insight Report: The Global Competitiveness Report 2013–2014*, Geneva: World Economic Forum.
- Schwab, K., 2014. *Insight Report: The Global Competitiveness Report 2014–2015*, Geneva: World Economic Forum.
- Schwab, K., 2015. *Insight Report: The Global Competitiveness Report 2015–2016*, Geneva: World Economic Forum.
- Schwab, K., 2016. *Insight Report: The Global Competitiveness Report 2016–2017*, Geneva: World Economic Forum.
- Wright, C., Mannathoko, C. & Pasic, M., 2009. *UNICEF Child Friendly Schools Manual*. [Online] Available at: [http://www.unicef.org/publications/files/Child\\_Friendly\\_Schools\\_Manual\\_EN\\_040809.pdf](http://www.unicef.org/publications/files/Child_Friendly_Schools_Manual_EN_040809.pdf)

# Building Performance Evaluation of an Office Building in the UK- A case study of a university office building

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**Abstract:** The efficiency of office building design has become increasingly important in recent years. This is both due to the negative impact inadequate office building design may have on the built environment due to excessive mechanical heating and cooling systems, as well as the impact of unsatisfactory thermal comfort and poor indoor thermal condition on the occupants' health, wellbeing and productivity at work. With the aim of discovering how the thermal comfort, and energy performance of a modern office building can be improved, a study of an existing office building, at one of the London based universities, and its occupants is carried out. The occupants had already reported several issues with the indoor environment that causes discomfort in summer and winter seasons, hence the significance of the study. An analysis of potential issues reported concerning occupants' thermal comfort and building energy performance is investigated to develop a potential design intervention to improve both aspects. In order to solve this problem, a quantitative research design has been adopted including three methods for data collection and analysis. Initially an occupant survey is carried out including questions on occupants' activity, comfort and overall experience with the indoor environment. Secondly, data loggers have been placed in the building to record air temperature and relative humidity for one whole year. At a later stage, computer simulation modelling will be used to further explore inefficiencies in the building and the potential interventions to improve the building performance and occupants' thermal comfort. The initial results show that different parts of the building have been deemed uncomfortably warm with a lack of air movement in the summer months and unacceptably cold and draughty in the winter months. This is expected to be due to the lack of adequate natural ventilation in some areas, and the lack of adequate heating and cooling in some rooms.

**Keywords:** Thermal comfort, building performance, questionnaire survey, field monitoring, office building

## Introduction

The success or failure of a building design depends largely on the satisfaction of the building's occupants. In the case of office buildings, if occupants are not comfortable this can impact on their health, wellbeing and productivity (Amasyali & El-Gohary, 2015). Therefore assessing whether the needs of the occupants have been met after they have inhabited the space for at least a year can be a useful tool to examine the suitability of the design. Post occupancy evaluation (POE) can prove a beneficial tool to ascertain whether a building has met its design aims or whether improvements to aspects such as thermal comfort and indoor environmental quality (IEQ) would be advisable (Walbe Ornstein & Ono, 2010). It is possible that some relatively modern buildings designed and built to meet the current building regulations at the time of construction may not be considered comfortable to the users. This type of problem may occur because part of the building regulations is designed to limit the heat transmission through building materials. However, building regulations may not oblige designers to consider the unique qualities of individual buildings which also affect its internal temperatures. Each building has its own microclimate which is impacted by its surrounding buildings, orientation, geographical position, and so on (Gaspari & Fabbri, 2017). This may mean that in order to design and produce buildings which are comfortable for the occupants; more attention to detail is needed to discover the optimal geometry, orientation, fabric, etc. of the building by the designer in order to create healthy and efficient buildings. This may prevent situations in which

buildings are discovered to have thermal comfort issues post occupancy. These issues may then be more difficult and costly to rectify than they would be if the prospective issues were addressed at design stage, for instance if façade retrofit is required (Martinez et al, 2015). Hence, if thermally inefficient designs are used, buildings can be very resource intensive and expensive to run. For example, Lin et al (2016) suggested much greater attention is needed in the design of sustainable office building facades in order to reduce the use of air conditioning systems. However, even when these factors are considered at design stage, buildings with thermal comfort issues provide a learning tool in which design professionals can learn from the faults made, and learn to better understand people's needs which can improve future designs of similar buildings (Hens, 2009). For example, Mlecnik (2012) carried out a post occupancy study of passive housing employing a questionnaire of the inhabitants. Passive houses are designed to be very air tight, while mechanical heating and ventilation is designed to regulate the internal temperature to a comfortable level throughout the year. The study found that some people had issues with overheating in summer and installed air conditioning. This information can be used to improve future passive houses. If buildings suffer from internal overheating and stale air in the summer months and unacceptably cold temperatures and draughts in the winter months then this will probably have implications on energy use where occupants try to achieve comfort levels. This may be exacerbated by the effects of climate change as temperatures rise. For example, Shibuya & Croxford (2016) found that there has been an increasing energy demand for heating and cooling in office buildings in Japan in recent years. This, in turn, increases operational costs for the building owner and/or its tenants as well as increasing the negative impact of the building on the environment.

The purpose of this paper is to investigate the efficiency of a university office building to fulfill its purpose as a comfortable and productive working environment. This will be tested utilising a quantitative methodology involving a questionnaire of the building's users, data loggers measuring the air temperature, relative humidity (RH) and lux levels of different areas of the building and in a further stage a model of the building using Design Builder software in order to test the existing thermal efficiency of the building and explore potential interventions that could improve the thermal efficiency of the building.

## **Literature review**

### ***Energy Efficient Design of Office Buildings***

In recent years, increasing numbers of designers and clients have recognised the huge negative impact that the built environment imposes on the environment through carbon emissions both during the construction and operation phases (Alves et al, 2017, Jradi & Jorgensen, 2017, Wang et al, 2017). The positive outcome of this is a widespread shift in paradigm, where many buildings have been designed with sustainability as a primary concern. Some examples of this can be found in London where there are numerous BREEAM (Building Research Establishment Environmental Assessment Method) and a few LEED (Leadership in Energy and Environmental Design) rated buildings. 7 Air Street in London achieves BREEAM outstanding where the design includes sustainable attributes such as an innovative fuel cell technology heating system, a green roof and extensive cycle provision for staff. The Hub in London also attained BREEAM outstanding. Sustainable design features included a metering system to reduce electrical,

heating and cooling energy use, low or no VOC or formaldehyde in the internal finishes and increased cycling facilities. 240 Blackfriars Road, London obtained the LEED platinum rating. Sustainability features include mechanical heat recovery via a thermal wheel, PV panels on the roof and an efficient building fabric with solar control glazing. Despite these efforts, Argelis & Papadopoulos (2010) contended that endeavors to produce environmentally friendly and low energy buildings may also have the unintended effect of worsening indoor air quality and the thermal comfort of the occupants. Some factors which may cause the worsening indoor air quality are that buildings, particularly office building, may have become increasingly air tight and increasingly artificially heated and cooled and may have fewer operable windows.

The British Council for Offices (BCO) stated in their report on the health and wellbeing of office workers that in 2014-2015 23 million days were lost as a result of illnesses caused by or caught at work. They concluded that the place people work in has a significant impact on this due to factors such as poor ventilation, high levels of gases such as carbon monoxide and carbon dioxide and substances such as formaldehyde (BCO, 2016). Further, Behzadi & Olawale Fadeyi (2012) stated that low ventilation rates can be correlated to the reduction in the productivity and health of office workers. In addition, more buildings have an open plan layout which needs to accommodate for many people with differing comfort levels, and there is an increasing use of electrical equipment which emit sometimes unwanted heat and light (Sakellaris, I. et al, 2016). On the contrary, Lin et al (2016) concluded in a comparison of the indoor air quality of office buildings that were intended to be environmentally friendly and standard buildings that people were more satisfied with the thermal comfort and indoor air quality in the environmentally friendly offices than the standard offices according to their survey. However the difference in the actual energy consumption of the green buildings assessed was not significantly different to the standard buildings they were being compared to. Thus, the design intentions to make them green buildings may not have materialised in reality. Chappells & Stove (2005) stated that UK building regulations are designed to minimise draughts and improve insulation, yet the regulations may well require improvements so as to address overheating issues in summer. In this study, they suggest including shading and natural ventilation requirements in the building regulations to account for better IEQ.

Therefore, the post occupancy evaluations (POE) of buildings to assess their success in terms of both the energy efficiency and the comfort of the user are crucial, both to check that the building is fit for purpose and performs as designed. Despite this, post occupancy evaluations are rarely carried out and the same anomalies may continue to occur (Meir et al, 2009). There are several different methods of POE including building performance modelling (BPM), occupant satisfaction surveys, walk-throughs and observations and monitoring of temperatures, humidity and so on during occupation. Oduyemi & Okorch (2016) argue that many of the mistakes that designers make relating to thermal comfort and energy efficiency can be negated through the use of BPM at the design stage. Whilst BPM is a useful tool to analyse design solutions and predict comfort, the assessment of occupants' satisfaction after the building has been handed over to the client will let the designers know if the building actually performs as intended. This knowledge can feed back into and strengthen the design process and BPM of prospective building projects. For example, Ohba & Lun (2010) found that building simulations cannot yet accurately emulate air flow in order to assess the comfort of

naturally ventilated buildings. Therefore POE could be used to test the accuracy and validate computer simulation results.

### ***Office Building Design for Productivity and Thermal Comfort***

As stated by Hauge, et al. (2011), the indoor environment comfort of building users in terms of thermal, humidity, air movement, light, and noise is very important to the building performance, especially in the case of office buildings. This is because these factors can affect occupants' health, wellbeing and productivity which can have an impact on businesses economically. Therefore, the energy efficiency of buildings and the comfort of occupants need to be considered together in order to create successful designs. Ng & Akasah (2013) conducted research on office buildings which were designed to be highly sustainable and energy efficient. They utilised a post occupancy questionnaire involving the occupants of office buildings which had received sustainability awards and ratings such as LEED, in order to determine the comfort and indoor air quality of the buildings. They found that buildings which achieved a sustainability rating would not necessarily perform well with regards to the perceived comfort of the occupants and indoor air quality. They argued that people's perception of comfort is not as valued by building owners as energy consumption in the construction and the use of the building. This is because it is easier to quantify the economic value of those factors compared to the economic value of occupant satisfaction and productivity. However, due to its impact on productivity, a lack of thermal comfort can have an economic impact and the lessons learned from POE studies could provide a useful tool in designing energy efficient offices in future. Corroborating with this view, Niemela (2017) analysed the cost effectiveness of different renovation options on a 1980s office building based on occupant productivity upsurge. The study found that the comfort of occupants and their productivity were closely related; hence investing in occupant comfort had a significantly positive economic effect.

Whilst BPM can be used at the design stage to gauge thermal comfort levels, one factor that could not be ascertained through building simulation alone is people's ability to adapt to outdoor temperatures. Pagliano & Zangheri (2010) discerned through occupant satisfaction surveys in actual buildings and in laboratory conditions that people's thermal comfort levels adapt to external temperatures, meaning people were able to be comfortable in higher temperatures in summer and lower temperatures in winter. This type of information discovered through POE can be used in BPM in order to improve its effectiveness and accuracy. Hens (2009) found through an occupant comfort survey that more people were dissatisfied than was predicted based on standard comfort levels. However they noted that occupants may exaggerate their discomfort in order to encourage improvements to their work environment. Conversely, if occupants are trying to encourage change then they must be dissatisfied with their environment. Chappells & Shove (2005) found that building regulations and policy makers sustain a narrow and therefore resource intensive ideal level of comfort. If this was more adaptive to unique requirements, buildings may be more comfortable and have less of a negative impact on the environment.

However, Rupp & Ghisi (2017) questioned the use of predetermined adaptive temperatures based on outdoor temperature alone as they found that cultural and behavioural factors unique to each region had a bearing on people's adaptation to changing temperatures. People in more developed countries were less accepting of warmer and colder temperatures.

Whereas, people in developing countries have been found to have a wider comfort band and tended to be more forgiving of building performance shortcomings. Additionally, people in naturally ventilated buildings are more adaptive to changing temperatures than those accustomed to air conditioned buildings (Gallardo et al, 2016). Baird (2010) noted in an assessment of the POE of the Torrent Research Centre in India that; *“the generally positive user feedback to overall temperature for all three seasons is particularly significant, given the indoor temperature ranges that are higher than those deemed acceptable in air-conditioned and western contexts”* (Baird, 2010, p.321).

### **Occupant Behaviour and Energy Consumption in Office Buildings**

Surveys regarding occupants' perception and behaviour provide a highly valuable tool to gauge whether building designs are producing unintended behaviours in people due to a miscalculation of comfort. Langevin et al (2016) studied human behaviour in relation to energy use in office buildings. They incorporated human behaviour into BPM. However these were based on statistical behavioural models, so how accurately they represent how actual occupants would behave in a specific building is unclear. Thus, incorporating the actual occupants' behaviour in relation to thermal comfort into BPM could provide a clearer picture of the effectiveness of interventions aiming to improve thermal comfort. A methodology developed by Building Use Studies (BUS) is a post occupancy evaluation questionnaire aimed at office buildings users in order to establish how the building is performing. This is in relation to; thermal comfort and ventilation, lighting and noise, personal control, space, design and image, perceived productivity and how occupants travel to work. The aim of the methodology is to highlight areas which could be improved. This type of methodology could be used alongside building simulation and data logging to get a full picture of the efficiency of a building.

An unintended outcome of buildings which do not provide indoor comfortable, is that occupants may take measures such as using heating and cooling excessively in order to gain a satisfactory level of comfort (Painter et al, 2016, Langevin et al, 2015). This will clearly undermine the energy efficiency of the building's design and performance. However allowing occupants some control over their environment can improve the energy efficiency of office buildings. For example, Li et al (2014) studied buildings which took into account occupant behaviour when designing energy efficient office spaces. They concluded that allowing occupants to control their own heating, lighting, electrical equipment and ventilation and encouraging them to behave sustainably, such as encouraging them to turn off lighting when it was not in use, had a significantly positive impact on the energy efficiency of the building. Furthermore, assuming levels of comfort and controlling heating and cooling centrally can lead to an excessive use of energy. Gallardo et al (2016) assessed the thermal comfort of an office building in a temperate environment using an occupant satisfaction survey and recordings of temperature, air velocity and relative humidity. They found that if the use of mechanical heating and cooling were judged by the recordings alone then mechanical heating and cooling would be required. However, the survey revealed that people were more comfortable than expected and would not require mechanical heating or cooling. Therefore it is advantageous to ascertain the behavior and the opinions of the occupants in order to effectively judge the thermal comfort and the energy efficiency of buildings.



## **Research Methodology**

The aim of this study is to determine the thermal comfort of an existing office building. This is so that the information gained in this study may be used in further studies to discover optimal strategies for improving the comfort of the office building, in order to make it more energy efficient and enhance the wellbeing, health and productivity of the occupants. This study will achieve this through a quantitative research methodology with concurrent data collection techniques applied to a case study building.

### ***Case Study: University Business Unit Building***

An office building located in one of London's universities has been selected as the case study as there have been a number of complaints received from the occupants regarding the lack of air movement and overheating of some of the offices in the summer, and the uncomfortably low temperatures of some offices in the winter. Additionally, the ground floor reception, café and seating area had reported problems with draught and uncomfortable temperatures in winter leading to the areas being underused. This building was built in 2006 and had refurbishment work at a later date. It was constructed with steel frame and has metal cladding. The building comprises three floors including a three-storey atrium. It contains 1098 square metres of office space with 75 businesses based there. The building is generally occupied from Monday to Friday between the hours of 9am to 6pm. The building is busier from September to June during the university's term time, but is used throughout the year by staff, who use some of the offices and laboratories, and businesses that rent the offices. The building is surrounded by a four-storey high building to its south, a 3-storey building to its east and a 2-storey building to its north. There are no buildings to its east.

### ***Occupant Survey***

The first research method used in this study is an occupant survey. Occupants were requested to fill in a digital or paper questionnaire including questions on occupants' usage patterns and behavior, perceived comfort, perceived indoor air quality, and any other issues experienced in the building. This is a mainly quantitative survey with close-ended questions with a couple of qualitative open-ended questions. Questions relating to comfort were asked on a five or seven point scale e.g. for the question '*How do you generally feel in your office during the summer season?*'. Answers ranged from cold to hot with neutral in the middle. Occupants were also asked how they adjusted their environment to make it more comfortable, e.g. occupants were asked when they opened windows and if they had any additional heating or cooling appliances in their offices such as fans or electric heaters. Occupants were also asked open ended questions such as; '*How do you think the thermal comfort of your office could be improved?*'. The questionnaire was distributed to the building users over a period of 4 weeks in July. Only 37 responses were received due to many users being on annual leave.

### ***Data Monitoring***

The second research method employed is data monitoring of internal physical parameters including; air temperature and relative humidity levels using Hobo data loggers. Altan et al (2013) utilised a similar methodology on their study of indoor air quality of homes in Scotland. This allowed them to compare the actual air temperature and relative humidity levels in the homes against the acceptable levels and graphically represent this for analysis. This provides a

simple methodology to find areas which require improvement or further investigation in order to improve conditions. The physical parameters are measured at 30 minutes intervals from July 2017 and expected to continue until July 2018. There are four data loggers positioned on the ground floor including the lobby, the reception, café and seating area. This is because the occupants are normally not satisfied with the thermal comfort in these areas on the ground floor. These areas should be welcoming and comfortable and are important to the success of the building, as it has the potential to be a place where people from the businesses meet and have their lunch and is the first place the users will experience when they enter the building. In addition, five data loggers are placed in the office units on the ground, first and second floors. Three of them are placed in the ground, first and second floor corridors leading to the external businesses offices. One is placed in the atrium on the second floor and one is placed inside one of the offices on the first floor, which is one of the most problematic rooms. These offices are used by university staff or are rented to external businesses and these areas are also important to the success of the building. If the business unit areas are not thermally comfortable for the users it might reduce the health and productivity of the staff and as a result the current or prospective businesses may not remain in the building for the long term. CIBSE Guide A states that the comfortable operative temperature for offices in the winter months is between 21°C and 23°C, assuming for 0.9 clothing levels and 1.2 metabolic levels. In the summer months, they stipulate comfortable operative temperatures are between 22°C and 25°C, assuming for 0.7 clothing levels and 1.2 metabolic levels. Moreover, a minimum air movement rate is suggested to be 10 l/s per person and relative humidity levels between 40% and 70% are generally acceptable. In the non- air conditioned rooms relative humidity levels of 30% may be acceptable. The data loggers will remain in place for one year in order to have a full picture of the thermal comfort throughout the year.

## **Results and Discussion**

### ***Occupants' survey***

As mentioned previously, a questionnaire-based survey was conducted in the case study building during the summer while the indoor thermal comfort variables for the summer months were being measured. Overall 37 questionnaire forms were completed by the users as the building was occupied by this number over the summer period. The results show that 63% generally felt hot in the summer in their office, while 18% felt warm. This indicates that the majority of the respondents were not satisfied with the indoor thermal environment during the working hours in the case study building during the summer season. In addition, in response to the question concerning rating the air movement in their office while the windows are open in summer, 54% felt it was either very still or still while only 14% reported it was breezy. This suggests that the majority of the respondents felt that there was a lack of air movement in their office space even when the windows were open. Additionally, the vast majority of respondents stated that they opened their windows at all times during the summer. Moreover, there were mixed responses to the question concerning people's experience with air humidity in their office during the summer with 41% reporting they would rate it as very humid and humid, while only 16% rated it as dry or very dry, while 43% reported it as neutral. In order to understand whether occupants were using additional cooling methods in their offices, and if the cooling

methods they used in their offices were inadequate, they were asked if they had any secondary cooling systems in their offices. The result shows that the majority of the respondents had a secondary cooling system in their office; 63% having portable fans while 18% had portable air conditioning units. Table 1 summarises the main findings of the survey that conducted in the summer season.

Table 1. Summary of main findings of questionnaire survey for summer season

Thermal Perceptions	Air Temperature		Air Movement		Relative Humidity		
	Warm	Hot	Still	Breezy	Humid	Dry	Neutral
Respondents Percentages	18	63	54	4	41	16	43

With regards to the winter season, 55% of the people surveyed said they felt cold or very cold in their office, 17% responded neutral, while only 8% responded they felt warm. Furthermore, 62% reported they had electric portable heaters in their offices when asked about the secondary heating system in their office. This would also suggest that the offices are uncomfortably cold in the winter months so they had to bring in additional heating sources which increase the heating energy demands in the cold winter months. Therefore, the data loggers will be kept in the office spaces throughout the winter months to further understand the thermal comfort issues. Similarly to the summer season, half the respondents answered they felt the air was either very still or still, while only one person responded very breezy and three people responded breezy to the question '*How would you rate the air movement in your office during winter?*' This would again suggest that the respondents feel there is a lack of air movement in the offices throughout the year. Moreover, people surveyed were asked how they would suggest the thermal comfort of their offices could be improved. Nearly half the respondents suggested the installation of air conditioning system in the offices. Some of the other responses included more heating, more control over the temperature, better insulation, replacement of the metal roof, more windows and an improvement in air flow rate.

### **Field Monitoring**

As mentioned previously, the thermal comfort variables of the case study building including the indoor air temperature and the indoor relative humidity levels have been monitored with data loggers on the ground floor and the business units of the building for one year to assess and optimise the building performance and the occupants' thermal comfort. The focus of this paper is on the month of August for the on-site monitoring to evaluate the thermal comfort and thermal performance of the business unit internal corridors on three floors, as well as the reception area on the ground floor including lobby, seating area, seminar room, and the main reception. Figure 1 presents the location of the data loggers in the case study building.

The results of the field monitoring of indoor air temperature and RH levels on the ground floor in August 2017 (figures 1 and 2) indicate that although the indoor RH levels fluctuated significantly they mostly remained within the comfort band. However, the indoor air temperature sometimes dropped below the minimum comfort temperature for summer, which is 22°C, in the reception area. This may be because the seating area is next to the external doors which are opened and closed on a regular basis throughout the day increasing the air flow rate and as a result causing heat loss on the ground floor. It has been noticed that some of these instances of under heating did occur outside office hours so this does not affect office workers' comfort levels. However, there were instances in which the low temperatures

occurred during office hours. This was an expected result as the occupants of the ground floor reported problems with temperatures becoming too low in the winter months; they did not report any problems with overheating in the summer. Data monitoring of the ground floor spaces will continue throughout the winter period to understand if and reasons why the temperature falls significantly below the comfort range for offices during these months.

In contrast to the measured indoor air temperature on the reception area, the monitoring results of the internal corridors of the business units show that some of the measured area are normally above the maximum comfort range in summer (Figure 3). The results show that the indoor air temperature on the second floor is normally above the maximum comfort band for summer. In addition, in the 1<sup>st</sup> floor corridor, the indoor air temperature was normally just below the maximum comfort band and was sometimes above this range. However, the indoor air temperature stayed within the comfort band on the ground floor corridor.



Figure 1. Floor plans of the case study building presenting the location of the data loggers

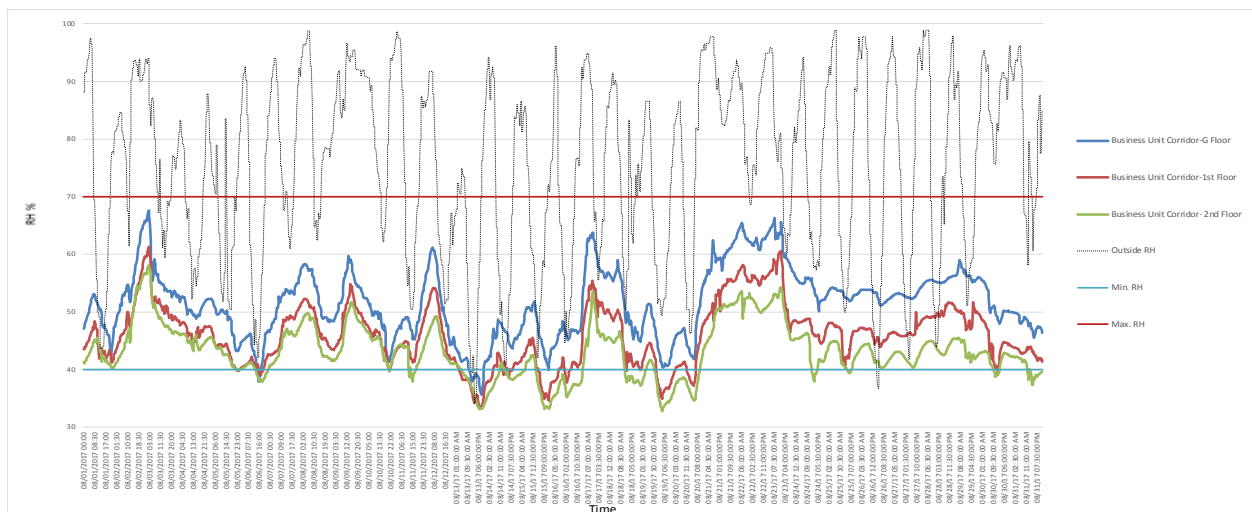


Figure 2. Indoor RH of the Business Unit corridors of the case study in August 2017

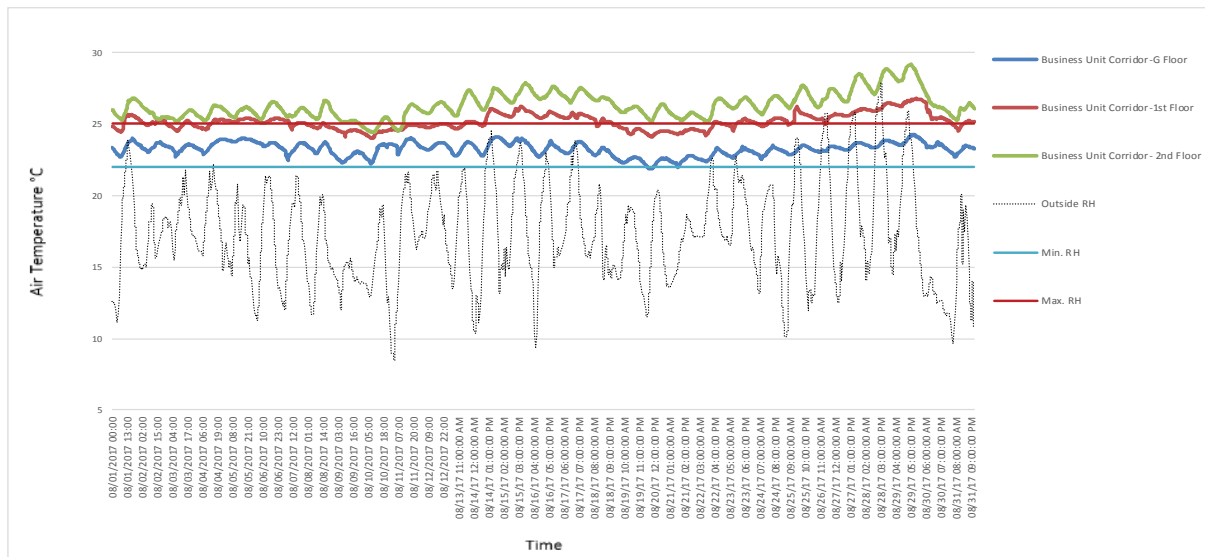


Figure 3. Indoor air temperature of the Business Unit ground, first and second floors in August 2017

Generally, the data loggers' results show that the higher outdoor temperatures, the worse the indoor thermal conditions in the office units became. In terms of the relative humidity in August, the measured RH levels are normally within the comfort ranges (Figure 2). However, sometimes the measured RH levels fell below the comfort range. The 1<sup>st</sup> floor corridor fell below minimum comfort levels for six days in this month, and was also at the high end or above maximum comfort levels for the measured indoor air temperature throughout the recorded period. The results of the field measurements show that the main areas of concern in terms of thermal comfort of the occupants are the business units' corridors on the 2<sup>nd</sup> and 1<sup>st</sup> floors. As a result, the main focus of the next stage of this study on building evaluation using DesignBuilder simulation tool will focus on these problematic areas.

### Research Limitations

The results were limited by the number of respondents to the questionnaire. As there were only 37 respondents during the summer season, it cannot be assumed that all building occupants agree with the findings. The questionnaire will be redistributed during the working hours in cold season as well, when the building is fully occupied to get a larger number of respondents so that conclusions can be drawn with more accuracy. It should be noted that 45% of respondents were white, 16% were Asian, 8% were black, 6% were Pakistani or Bangladeshi, 3% were Latin and 3% were Chinese. In addition, 19% decided to give no comments. Therefore, the results may be biased towards white people. 32% of respondents were aged 25 to 34, 30% were aged 35 to 44, 16% were aged 16 to 24, 11% were aged 45 to 54, 8% were aged 55 to 64 and 3% were aged 65 and above. There does not appear to be a bias towards any age group as this matches the ages of the building occupants.

### Conclusion

In conclusion, this study presents the results of the field studies of an office building at a London-based university in order to evaluate the building performance and thermal comfort of the occupants on the ground floor reception area and the business units' corridors on three

floors. The field studies include the questionnaire-based survey and field monitoring of thermal comfort variables including the indoor air temperature and the relative humidity levels during the summer month of August 2017. The field study results indicate that the thermal comfort of the case study building needs to be improved in summer months in order to fulfill its main purpose as a being a productive and healthy working environment for both permanent and temporary staff. The questionnaire-based survey results show that the respondents are not thermally comfortable in the business units as their offices were normally too hot for them in the summer months and too cold in the winter period. In addition, the measured indoor thermal comfort variables by data loggers have corroborated with the views of the respondents by recording indoor air temperatures normally above the maximum comfort levels or at the higher end of the comfort band throughout the data collection period.

The results show that the second floor business unit's corridor have the most problems regarding the overheating risk in summer months, while the 1<sup>st</sup> floor corridor was also shown to not comply with the comfort levels. The reception area on the ground floor appeared to remain within the comfort range throughout summer according to the questionnaire results. However, the thermal comfort issues were reported to be during the cold winter period on this floor. In addition, based on the field monitoring results the indoor temperature and relative humidity levels during the summer months on this floor were normally within the comfort band. Therefore, the data loggers will remain in place throughout the winter season in order to discover the thermal condition of this floor throughout the year including the winter and the summer periods. The second phase of this project is the building performance optimisation for energy efficient retrofit of the building in the short term. This is in order to provide a comfortable and productive indoor thermal environment for the staff and consequently reduce the building's energy loads both in winter and summer seasons. This is with the aim of encouraging business tenants to be inclined to remain in the offices for the long term.

## References

- Altan, H., Refaee, M., Han, L. & Noguchi, M. (2013). Measured Home Environment and Energy Consumption Compared to Accepted Standards. *ZEMCH 2012 International Conference*, 38, pp. 64-71. Open House International.
- Alves, T., Machado, L., Goncalves de Souza, R. & de Wilde, P. (2017). A methodology for estimating office building energy use baselines by means of land use legislation and reference buildings. *Energy and Buildings*, 143, pp. 100-113. Elsevier.
- Amasyali, K. & El-Gohary, N.M. (2015). Energy-related values and satisfaction levels of residential and office building occupants. *Building and Environment*, 95, pp. 251-263. Elsevier.
- Angelis, A. & Papadopoulos, A.M. (2010). On the evaluation of heating, ventilating and air conditioning systems. *Advances in Building Energy Research*, 4, pp. 23-44. Earthscan.
- Baird, G. (2010). *Sustainable Building in Practice. What the Users Think*. USA and Canada: Routledge.
- Chappells, H. & Shove, E. (2005). Debating the future of comfort: environmental sustainability, energy consumption and the indoor environment. *Building Research & Information*, 33, pp. 32-40, Taylor & Francis.
- Chen, J., Augenbroe, G., Wang, Q. & Song, X. (2017). Uncertainty analysis of thermal comfort in a prototypical naturally ventilated office building and its implications compared to deterministic simulation. *Energy and Buildings*, 146, pp. 283-294. Elsevier.
- Behzadi, N. & Olawale Fadeyi, M. (2012). A preliminary study of indoor air quality conditions in Dubai public elementary schools. *Architectural Engineering and Design Management*, 8, pp. 192-213, Taylor & Francis.
- Gallardo, A., Palme, M., Lobato-Cordero, A., Beltran, R.D. & Gaona, G. (2016). Evaluating thermal comfort in a naturally conditioned office in a temperate climate zone. *Buildings*, 6, pp. 27-47. MDPI.



- Gaspari, J. & Fabbri, K. (2017). A study on the use of outdoor microclimate map to address design solutions for urban regeneration. *Energy Procedia*, 111, pp. 500-509. Elsevier.
- Hauge, A.L., Thomsen, J. & Berker, T. (2011). User evaluations of energy efficient buildings: Literature review and further research. *Advances in Building Energy Research*, 5, pp. 109-127. Earthscan.
- Hens, H.S.L.C. (2009). Thermal comfort in office buildings: Two case studies commented. *Building and Environment*, 44, pp. 1399-1408. Elsevier.
- Jradi, M., Veje, C. & Jorgensen, B.N. (2017). Deep energy renovation of the Maersk office building in Denmark using a holistic design approach. *Energy and Buildings*, 151, pp. 306-319. Elsevier.
- K, R., Gupta, N., & Shet, H.N. (2016). Analysis of Measures to Improve Energy Performance of a Commercial Building by Energy Modeling. *International Conference on Green Engineering and Technologies*, 978, pp. 188-191, IC-GET.
- Langevin, J., Wen, J. & Gurian, P.L. (2016). Quantifying the human-building interaction: Considering the active, adaptive occupant in building performance simulation. *Energy and Buildings*, 117, pp. 372-386. Elsevier.
- Li, C., Hong, T. & Yan, D. (2014). An insight into actual energy use and its drivers in high-performance buildings. *Applied Energy*. 131, pp. 394-410. Elsevier.
- Lin, B., Liu, Y., Wang, Z., Pei, Z. & Davies, M. (2016). Measured energy use and indoor environment quality in green office buildings in China. *Energy and Buildings*, 129, pp. 9-18. Elsevier.
- Martinez, A., Patterson, M., Carlson, A. & Noble, D. (2015). Fundamentals in Facade Retrofit Practice. *Procedia Engineering*, 118, pp. 934-941. Elsevier.
- Lin, Y., Tsai, K., Lin, M. & Yang, M. (2016). Design optimization of office building envelope configurations for energy conservation. *Applied Energy*, 171, pp. 336-346, Elsevier.
- Meir, I.A., Garb, Y., Jiao, D. & Cicelsky, A. (2009). Post-occupancy evaluation: An inevitable step toward sustainability. *Advances In Building Energy Research*, 3, pp. 189-220. Earthscan.
- Mlecnik, E. (2013). Improving passive house certification: recommendations based on end-user experiences. *Architectural Engineering and Design Management*, 9, pp. 250-264, Taylor & Francis.
- Niemela, T., Levy, K., Kosonen, R. & Jokisalo, J. (2017). Cost-optimal renovation solutions to maximize environmental performance, indoor thermal conditions and productivity of office buildings in cold climate. *Sustainable Cities and Society*, 32, pp. 417-434. Elsevier.
- Ng, B-H. & Akasah, Z.A. (2013). Post occupancy evaluation of energy-efficient building in tropical climates-Malaysia. *International Journal of Architectural Research*, 7, pp. 8-21. ArchNet-I-JAR.
- Oduyemi, O. & Okorch, M. (2016). Building performance modelling for sustainable building design. *International Journal of Sustainable Built Environment*, 5, pp. 461-469. Elsevier.
- Ohba, M. & Lun, I. (2010). Overview of natural cross-ventilation studies and the latest simulation design tools used in building ventilation-related research. *Advances in Building Energy Research*, 4, pp. 127-166. Earthscan.
- Pagliano, L. & Zangheri, P. (2010). Comfort models and cooling of buildings in the Mediterranean zone. *Advances in Building Energy Research*, 4, pp. 167-200. Earthscan.
- Painter, B., Irvine, K.N., Waskett, R.K. & Mardaljevic, J. (2016). Evaluation of a Mixed Method Approach for Studying User Interaction with Novel Building Control Technology, *Energies*, 9, pp. 215-238. MDPI.
- Rupp, R.F. & Ghisi, E. (2017). Predicting thermal comfort in office buildings in a Brazilian temperate and humid climate. *Energy and Buildings*, 144, pp. 152-166. Elsevier.
- Sakellaris, I., Saraga, D.E., Mandin, C., Roda, C., Fossati, S., De Kluizenaar, Y., Carrer, P., Dimitroulopoulou, S., Mihucz, V.G., Szigeti, T., Hanninen, O., De Oliveira Fernandes, E., Bartzis, J.G. & Bluyssen, P.M. (2016). Perceived indoor environment and occupants' comfort in European 'modern' office buildings: The OFFICAIR study. *International Journal of Environmental Research and Public Health*, 13, pp.444-459. MDPI.
- Shibuya, T. & Croxford, B. (2016). The effect of climate change on office building energy consumption in Japan. *Energy and Buildings*, 117, pp. 149-159. Elsevier.
- Walbe Ornstein, S. & Ono, R. (2010). Post-Occupancy Evaluation and Design Quality in Brazil: Concepts, Approaches and an Example of Application. *Architectural Engineering and Design Management*, 6, pp. 48-67.
- Wang, L., Xiaohong, L. & Brown, H. (2017). Prediction of the impacts of climate change on energy consumption for a medium-size office building with two climate models. *Energy and Buildings* <http://dx.doi.org/10.1016/j.enbuild.2017.01.007>.

# Multi-criteria optimization for better indoor environment in UK homes

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**Abstract:** The design of more comfortable and energy efficient indoor environments can be achieved when thermal comfort, daylight and ventilation are considered concurrently. In the UK, dwellings, through the enforcement of Part L1A of the Building Regulations the fabric performance is regulated while the other parameters are attended to only at planning stage. This research explores the implication and outcome of simultaneous compliance and multi-criteria optimization in the design of midrise apartment blocks. The outcome as a guideline adheres to the existing Part L1A regulation for fabric performance, BS 8206 and BR 209 for daylight & sunlight, the Part F and BS 5925 for natural ventilation and the TM52 for overheating risks. The research adopts a dynamic simulation method with climate based input for daylight and for overheating risk assessment. The guideline is the outcome of the post processing of the results generated from a dynamic and integrated script developed using the native grasshopper plug-in in Rhino to create a parametric model which is then modelled and tested using DIVA for daylight, Ladybug for accessing sunlight hours and overshadowing, the Honeybee on Energy Plus interface for calculating the thermal load, energy gains and losses and finally the maths component for checking against overheating. Single aspect apartments are evaluated to arrive at best fit ranges in terms of window to floor ratio for thermal comfort, window to wall ratio for daylight, effective aperture opening size for ventilation and spatial layout for sunlight. Visualization tools are developed to intelligibly comprehend the relationship between different parameters. The research tool is envisioned to provide information to designers, practitioners and students for educational and research purpose. The guideline aims to help designers to make better informed design decisions and appreciate the trade-offs between daylight, heating demand and ventilation.

**Keywords:** Research tool, Building regulations, Multi criteria optimization, Parametric design

## Introduction

The building regulation was first introduced in the UK in 1965 with the enactment of the Building Act. Since then, driven from differing motives of coal shortage to energy efficiency measures now, over the last 60+ years there have been many milestone that finally led to the current regulation of Part L1A for new dwellings.

Energy efficiency is an important parameter in the housing sector with the housing sector consuming over 29% energy (Palmer & Cooper, 2013) and contributing to 28% of CO<sub>2</sub> emission in the UK (Green peace). The majority of the energy usage is for space heating and as per the website; Carbon Independent, the average electricity consumption in UK is 4,800kWh and 16,000 kWh for gas alone (carbon independent).

The energy consumption in domestic sector of UK has increased by 3.6%, with the majority being contributed by gas consumption, 5.1% higher, reflecting additional heating requirement (Department for Business, Energy and Industrial Strategy, 2016). Between 2014 and 2015 the consumption of energy per household has increased by 2.6%, owing to the changing expected level of comfort from individuals (Department for Business, Energy and Industrial Strategy, 2016).

However, since the inception of the Site layout and planning BR209, in 1999 and later with code for lighting for building BS8206-2, daylight and sunlight has been identified as of

paramount importance to create better living space. Good daylight helps reduce unnecessary energy consumption during the day while also creating better indoor climate thus contributing to the feeling of well-being. The London housing guide mandates daylight factor of 1.5%-2%, based on room use (Technical Housing Standard- nationally described space standards).

Nonetheless sunlight has to be viewed with the perspective of solar gain and so are solutions different for different regions (due to the solar altitude and solar azimuth angle). It therefore requires understanding and relating to the sun path diagram. As per the Planning for Daylight and Sunlight' standards, main living room windows should receive at least 25% of the total Annual Sunlight Probable Hours (ASPH). It also recommends that at least 5% of the ASPH should be received during the period between 21st September and 21st March.

Apart from energy efficiency standards and access to daylight and sunlight, ventilation plays an important part in ensuring better indoor environment. Ventilation is essential not only for thermal comfort but for the basic requirement of fresh air supply for healthy living. The code of practice for ventilation and principles of natural ventilation was laid down in 1991 and is the basis that led to the Part F on ventilation as a standard regulation in the UK. The part F lays down minimum ventilation rates for air exchange in the room for mechanically ventilated rooms. The part F is also suited for office buildings where mechanical ventilation is opted over natural ventilation.

The Part L1 A of the building regulations has been revised as of April 2016 to make it more stringent in terms of limiting fabric performance; however the daylight requirement is left to the designer's discretion. As the building regulation are further tightened, to meet higher CO<sub>2</sub> reductions, architects and designers face greater coordination challenge with other parts of the design team given the lack of standard document that can be followed that enables being compliant to the Part L as well as meeting the daylight standards for better performing building.

There is no guideline which has considered all the three requirements of daylight & sunlight, ventilation and overheating risk in an integrated manner, in the UK. The project led to creation of an integrated evaluation tool which is then post processed to prepare from a guideline.

### ***Thematic area***

The research focusses on in-depth study of building regulations, standards and guidelines on the following:

#### **1. Fabric performance**

The final guideline as per the research objective ensures that it complies with the fabric requirement set in Part L1A, conservation of fuel and power in new dwellings. The dwelling fabric energy efficiency is adhered to by following the recipe approach as outlined in the recent 2016 amended document of the regulation.

#### **2. Daylight**

Currently, daylight requirements are only considered at planning stage. In order to ensure that these are considered at the design stage, the BS8206 and the BR 209 are discussed and elaborated on. The minimum standards as discussed in literature are maintained. Apart from the Annual Daylight Factor (ADF), Daylight Autonomy (DA) is also calculated to consider the dynamics of climate based daylight modeling.

#### **3. Sunlight**

The right to light and overshadowing are particularly important in residential project as it adds value to space, thus a place making agent. The BR 209 is used to calculate the Annual Sun Probability Hours (ASPH). Sunlight is important in site planning approach as well as in massing between spaces.

#### 4. Ventilation

The effective aperture opening is determined to arrive at area of aperture for minimum fresh air as well as for cooling during summer.

#### 5. Overheating risk

The form is assessed for overheating risk as per TM 52 guideline and mitigation developed depending on the severity of overheating.

### **Limitation**

It is the script development that is the core of the research as it lays the basis for the guideline. The script is validated using the procedure laid in AM11, however is limited to the author's knowledge on the subject.

### **Climate study**

The Köppen Climate Classification subtype for the climate of London is "Cfb" (Marine West Coast Climate). The city of London is located on 51.5072° N, 0.1275° W and is at 100 m to 245m from sea level.

The analysis is to put forth the inter-linkages between the sun, radiation, wind and sky condition which are critical to be analysed in parallel and not in isolation.

### **The sun, sky and light**

The position of the sun and sky condition affects the sunlight and the light reaching indoors. It is not the number of hours and time of the sunlight hours only but also the cloud cover that impacts radiation reaching the surface. The figure 1 shows the frequency of sky types.

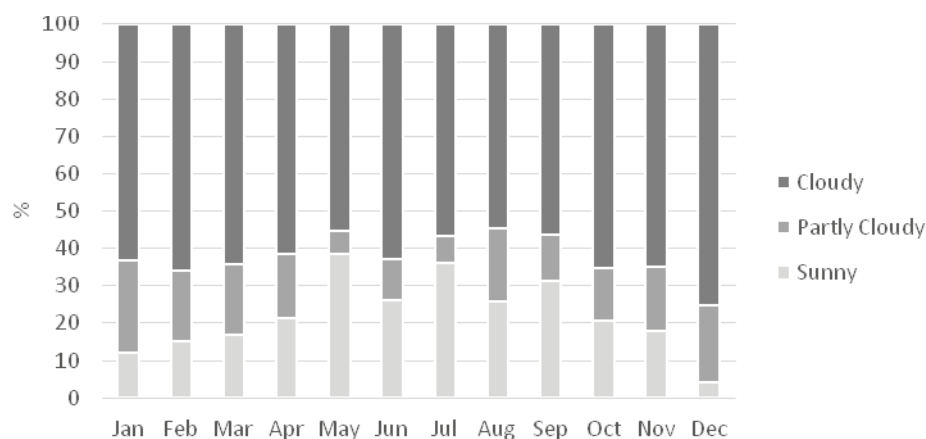


Figure 1: Frequency of sky types (source: Metornorm data)

The figure 2 shows that the intensity of the global horizontal radiation on the solstices and the equinox. The effect of the sun is not limited to its availability alone but also to the cloud cover (refer figure 3a) and that has a direct implication on the outdoor horizontal luminance (figure 3b). This in turn affects the daylight that we receive indoors.

The sky condition in London is mostly cloudy throughout the year and mostly during the winter season as such the direct horizontal radiation is much less compared to the horizontal radiation. So while the sun hours are less and the radiation less, the sky condition

is also poor, as such it would be desirable to have glazed areas on the south side and  $30^\circ$  on each side. It justifies the requirement as laid out in BR 209 for sunlight. However it also means that the rooms along this orientation are more likely to be overheated in summer, hence necessitating a balanced approach.

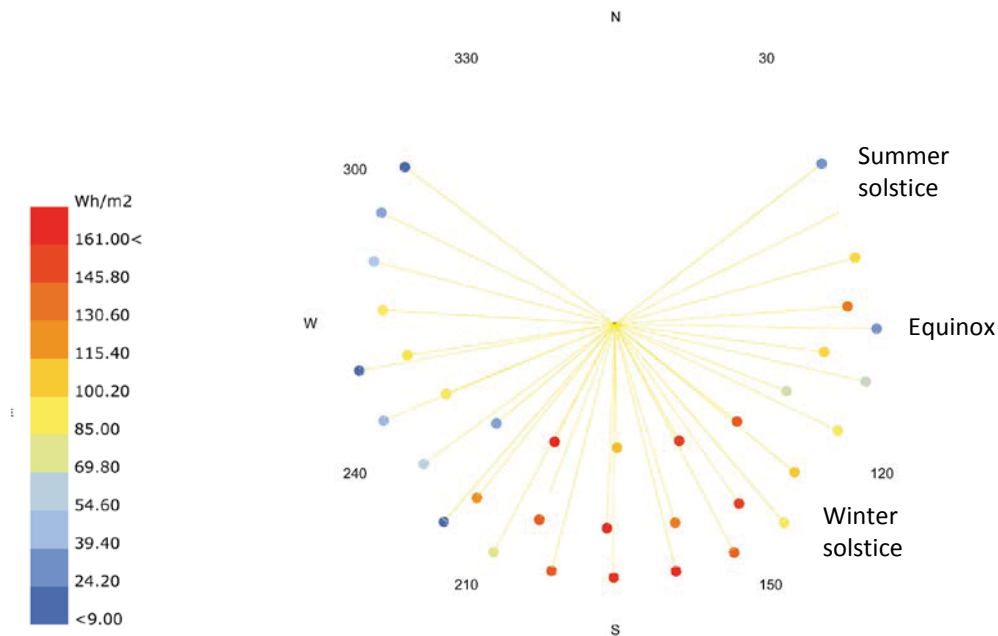


Figure 2: Intensity of global horizontal radiation on equinox and solstices

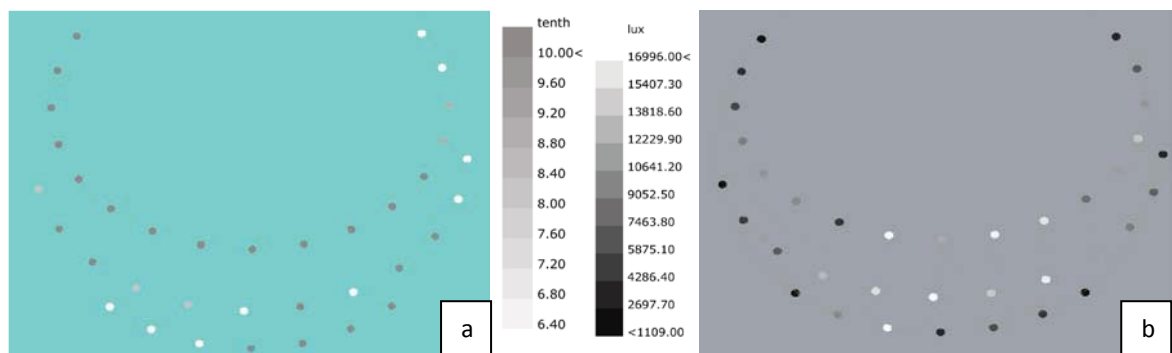


Figure 3: Sky condition (a) and global horizontal luminance (b) on equinox and solstices

### ***The sun, thermal comfort and wind***

The sun is the source of daylight and heat and as such the dissipation of heat is subject to the wind direction.

The figure 4 shows the monthly sun hours, the wind direction and the vertical radiation on the four cardinal directions. Though the prevailing wind direction in London is west or South west, the monthly wind rose suggests that for in the cooler season (from October to April) the building has to be shielded from cold wind from south to south west side. During the warmer season (rest of year) the building can benefit by orienting its window towards west. The graph distribution of the daily average global radiation on a  $90^\circ$  surface shows that the south side receives higher radiation from September until April averaging to around  $2.5\text{kWh/m}^2$ . The east and west planes receive similar radiation to each other while on July, it receives the highest radiation of  $6.5\text{kWh/m}^2$ . It can be concluded that

for addressing overheating risk from May until September, all except the north side facing plane has to be carefully considered.

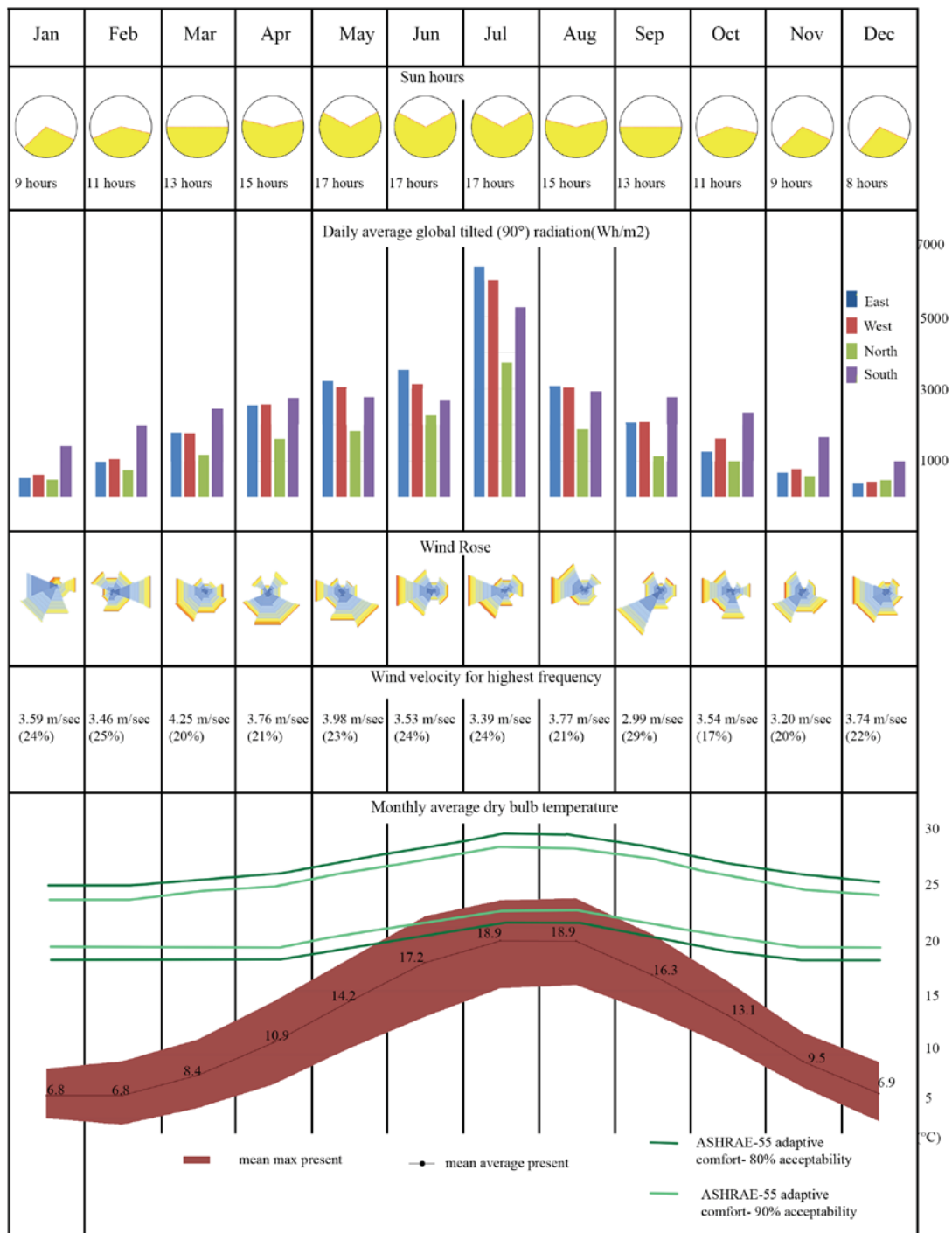


Figure 4: Monthly annual multi data study

In the urban context the wind direction is depended on the obstruction along its path and the context. Wind velocity can alter our perception of comfort. A careful consideration of the wind and sun can help achieve better indoor environment using low cost passive strategies.



## The tool

There are multiple requirements that a good design has to confirm to however these are rarely considered coherently. Each guideline/ regulations needs a set of condition to be fulfilled to ensure compliance like the TM52 requiring Design summer Year (DSY) file for evaluating overheating risk while Part L1a requiring Test Reference Year (TRY) for checking compliance for heating load. On the other hand, there is no mention of which weather file is to be used for daylight compliance.

A dynamic parametric tool helps the user to control the input variables and through an iterative process arrive at optimized ranges that will suit the design. The tool can perform all of the simulations simultaneously giving the modeller a better understanding on what the next optimization process has to be without losing sight of the result he/she does not want to change. For example, the modeller can change the effective aperture opening (for mitigating overheating issues) without changing the size of the window (thereby not affecting daylight factor or daylight autonomy).

The research tool developed adopts a dynamic integrated simulation method to analyse homes. The applicable rules, regulations and guidelines for UK housing for thermal, daylight, ventilation, sunlight and overheating issues are considered in the making of the tool (refer figure 5).

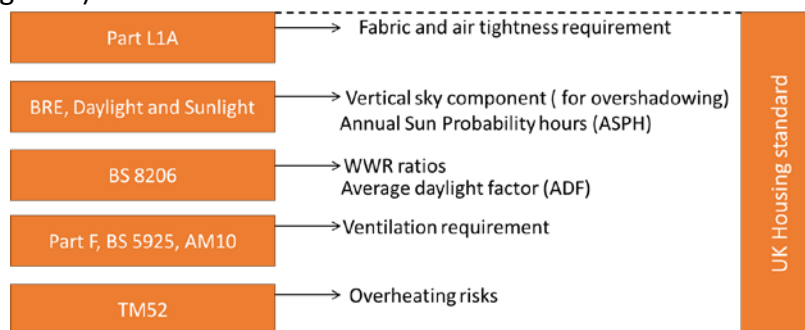


Figure 5: The multi-criteria requirement

There are specialised tools in the market that perform rigorous and specific simulations like the TAS for thermal performance. These are commercial tools, hence expensive to purchase and maintain. The other drawback is the scope of these software packages. For example, TAS can perform thermal simulation for energy demand with the EPW file however if the modeller is to analyse the overheating risk assessment then he/she will need to rerun the simulation with another weather file and compare. In other words, the simulation result is limited to the specific weather file only, figure 6 illustrates the drawback.

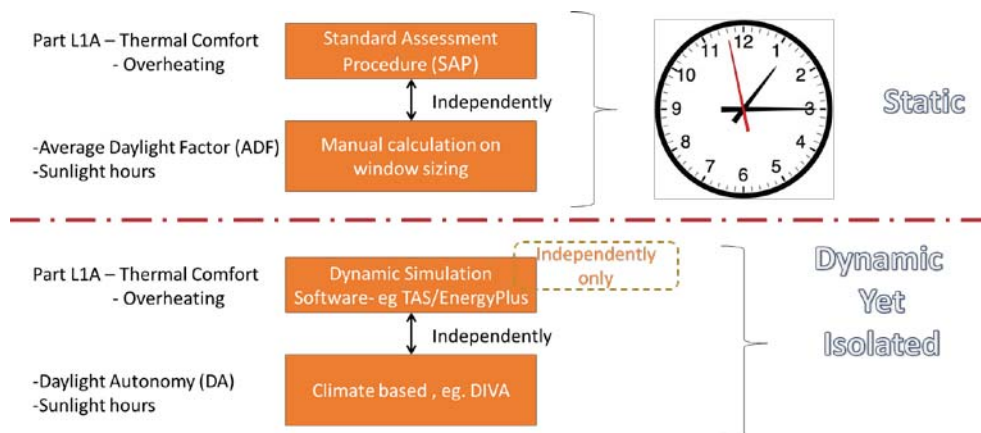


Figure 6: An overview of existing approach to building performance evaluation in UK Housing

The tool is developed using the native grasshopper plug-in in Rhino to create a parametric model which is then modeled and tested using DIVA for daylight, Ladybug for accessing sunlight hours and overshadowing, the Honeybee on Energy Plus interface for calculating the thermal load, energy gains and losses and finally the math(s) component for checking against overheating.

### **Applicability**

Currently there is no tool in the market that can run simultaneous dynamic simulation for a range of requirement as daylight, sunlight availability, heating load and checking overheating risk. It may be due to the sheer requirement to have different weather file to run the specific simulations.

The tool is used for building performance evaluation of mid-rise residential blocks for the current research. However, if the tool is parametrically developed changes as on number of floor height or size can be made to study high rise or low rise building or different sized apartments.

The tool can be used both as an analytical tool as well as a design tool. In the research the tool is used as a research tool and the findings used to develop a guideline. It is envisaged that further development of the tool can realize in developing the tool into a design supporting tool which will help architects, designers, house owners and planners to arrive at best fit ranges under certain set condition.

For simplicity, the tool considers the whole flat as a single zone, however as the tool is created using parametric user interface, the user can add wall and windows as per the requirement/ design (refer figure 7).

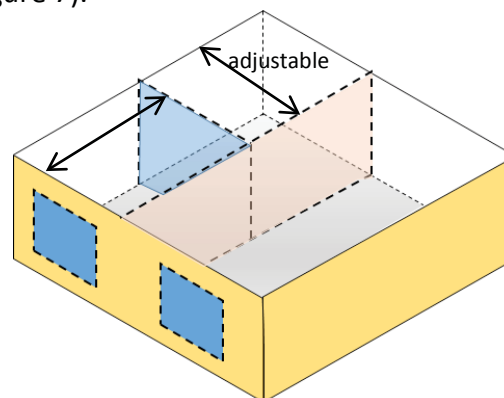


Figure 7: Illustration of parametric model

### **Tool Development**

Concisely, the tool analyses 6 different zones within a building developed parametrically, on the 8 cardinal directions with inputs (primary, secondary and tertiary). Compliance tests for the input are carried out and the best fit ranges are arrived at. The result is then post processed and optimization variables loaded into the tertiary input. The tertiary input is subject to change for optimization process.

The model is a parametrically designed 6 storied tall building (refer figure 8). A parametric context is built around the model with the following relationship;

The Height (H) is the height of the unit and the minimum height is set at 2.5 m which is the minimum standard applicable in UK (Technical housing standards – nationally described space standard, DCLG, 2015).

The room width and Depth are a function of the room height and in confirmation to the floor area as stipulated in the technical housing standards – nationally described space standard, DCLG, 2015, whereby

$$W \text{ (width of wall)} = xH$$

$$(D) \text{ depth} = yH$$

The Width of the window is a function of the width of the wall and a percentage of the overall width, whereby,

$$\text{Winwidth} = (0\%-90\%) * W$$

The width is confirmed and then the height of the window arrived at being a function of the Window to Wall Ratio (WWR). The wall area being

$$\text{Warea} = H * W$$

The height of the window is a function of the Warea, whereby if the WWR is 50%, then

$$\text{Winheight} = 50\% * \text{Warea} / \text{Winwidth}$$

The window height is based from the head height at 2.2 m (or as per requirement) off the ground (increasing downwards as the % of WWR increases). The start benchmark for the window being at the head height level helps to design for spaces that might not have provision to have normal windows. Further it helps to draw up the analogy of very large windows that present day houses are increasingly display. The figure 8 illustrates the relationship.

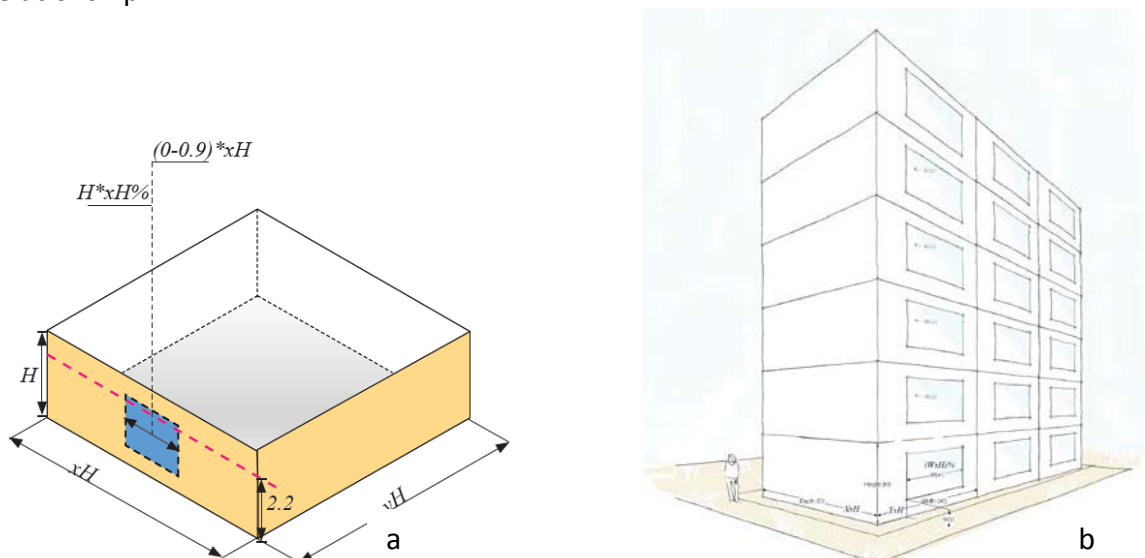


Figure 8: The typical zoned unit (a) and the test model (b)

The Context is based on the total height of the building and the road width relationship as derived from the literature review. The context is developed on all the four sides. The relationship is shown in figure 9.

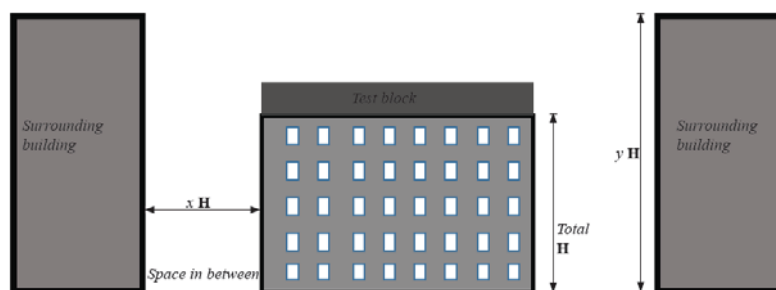


Figure9: The context creation

The figure 10 shows the simplified logical sequence of the tool



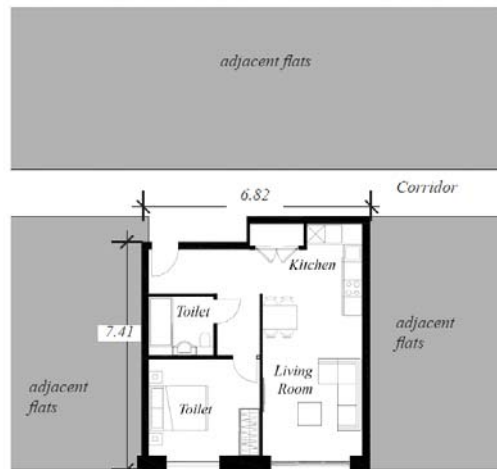


Figure 92: Reference model for validation

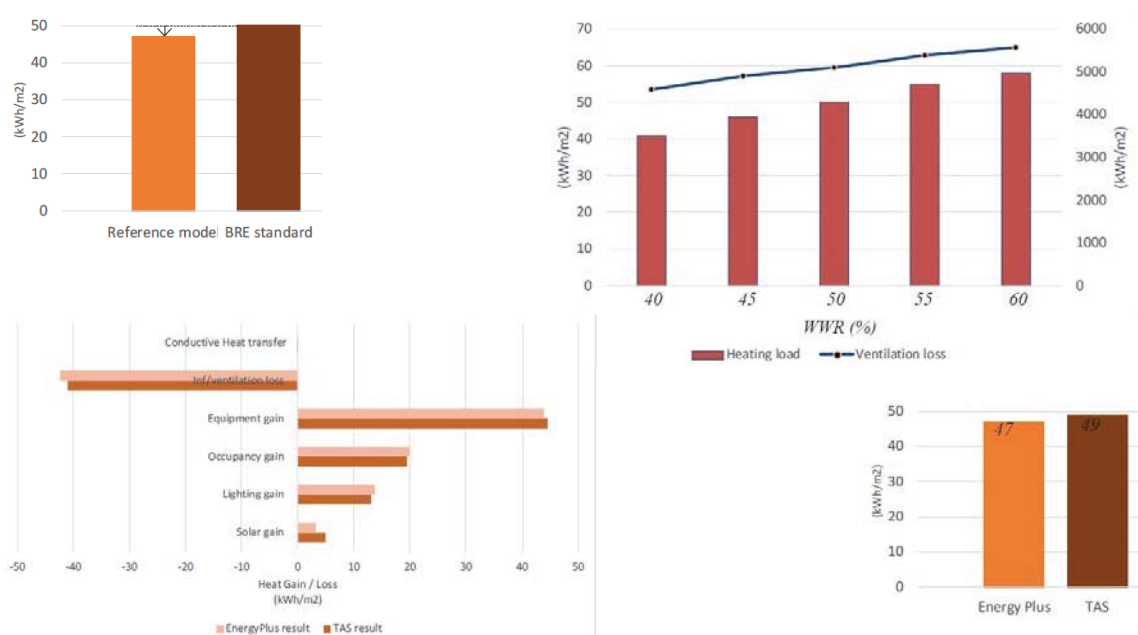


Figure 3: Empirical validation (a), Analytical validation (b), Comparative testing heat transfer(c), Comparative heating load (d)

## Conclusion

The Part L1A requires dwellings to be in compliance to the regulations using Standard assessment Procedure (SAP) which is a static simulation package. A dynamic simulation provides results that provide a clear picture on a day to day basis under different condition, thereby generating results that will help in making quality decision in shorter period of time. Currently the rules, standards and regulations are evaluated in isolation and at different phases of design which results in final design not being as envisaged by the architect.

A multi criteria approach helps in improving quality of decision making with explicit, rationale based approach that improves the overall performance of space. Designers tend to overly focus only on one specific area and overlook other interrelated impact resulting in design that need to undergo major changes while being put up for planning approval.

The tool developed is used to evaluate the multi-criteria; daylight sunlight, thermal comfort and heating load, all in one go, thereby giving more information to the designers to make an informed decision. The tool is based on a parametric user interface thereby allowing multiple scenarios. The tool has the potential to be developed into an analysis driven design tool. The tool is a first of its kind and it can assist designers in the design process through analytical findings for the parameters included in a single attempt.

The multi criterion takes into account the existing regulations and adds value to arrive at numbers to determine whether the other set of requirements are met in parallel. However as a designer one must be wary of the how the numbers can be sometimes misleading especially when it accounts for distribution of the results in a space. For example the daylight results can show an average of 2% but if the distribution is not even then irrespective of the good daylight value the actual performance of the space will be of poor quality with chances of glare.

While software(s) help determine if the various parameters as daylight, sunlight, thermal comfort and energy demand are met, it does not help to determine whether the space is going to positively contribute to the physiological and psychological experience of the user. The multi-criteria approach will help a designer to ensure that all aspects that contribute to better indoor environment are considered in parallel and the resultant design ensures a space that has better performance attributes. The designer can use the result to arrive at the best proportion for the various components of the room including the proportion of the glazed area with respect to the climate, context and orientation.

## References

- Baker, N. and K. Steemers (2002). *Daylight Design of Buildings*. James & James Science Publishers.
- British Standards, 2008. BS 8206-2:2008, *Lighting for buildings. Code of practice for daylighting*, s.l.: BSI.
- British Standard, 1991, BS5925, *Code of practice for ventilation principles and designing for natural ventilation*, BSI
- Building Regulation 2010, L1A Conservation of fuel and power in new dwellings, NBS, London
- CIBSE, 2005. TM36: *Climate Change & the Indoor Environment: Impacts & Adaptation*, London: CIBSE.
- CIBSE (2006). *Comfort*. CIBSE Knowledge Series KS 6. Chartered Institution of Building Services Engineers, London.
- CIBSE (2008). TM46: *Energy Benchmark*, CIBSE, London
- CIBSE (2013), TM52: *The limits of thermal comfort: Avoiding overheating in European building*, CIBSE, London
- CIBSE Application Manual AM10 (2005), *Natural ventilation in non-domestic building*, Page Bros, Norwich
- CIBSE (2015), AM11, *Building Performance Modelling*, CIBSE, London
- City of Westminster (2013), *Westminster City Plan Consolidated with all changes since November 2013*, London
- Committee on climate change. (2016). *UK climate action following the Paris Agreement*. London: Committee on climate change.
- Department for Business, Energy & Industrial Strategy (2017), *Energy Consumption in the UK*, London
- Code for Sustainable Homes, Technical Guide November*
- Technical Housing Standard- nationally described space standards*, London: Communities and Local Government Publications.
- Energy saving advice community (2016) Available at: <http://www.thegreenage.co.uk> (Accessed: 19 December 2016).*
- Etheridge, D. (2012). *Natural Ventilation of Buildings: Theory, Measurement and Design*. Wiley.
- Gia (2017), *Guiding Light: unlocking London's Residential Density*, London
- James Ford (2015), *Overheating in homes- Design strategies*
- Jeldwen (2017), *External joinery technical specification guide*, Leicester



- Law, D., Rogan, D., Zarges, J. & Zoghaib, D., 2007. *Emerging typologies*. In: *Housing and the City*. London: LSE, pp. 57-87.
- London Borough, n.d. *DAYLIGHT, SUNLIGHT, OVERSHADOWING & SOLAR GLARE*, London: s.n.
- Mayor of London, 2010. *London Housing Design Guide, Interim edition*, London: London Development Agency.
- Mooney, D., n.d. *ADVANCES IN DAYLIGHT SIMULATION*, London: s.n.
- Nicol, F., n.d. *TM52, The limits of thermal comfort: avoiding overheating in European buildings*.
- Passivhaus, n.d. *Passivhaus Primer – Designer's Guide: A guide for the design team and local authorities*, Hertfordshire: British Research Establishment.
- PEEL, M.C., FINLAYSON, B.L. and MCMAHON, T.A. (2007) 'Updated world map of the Köppen-Geiger climate classification', *Hydrology and Earth System Sciences Discussions*, 4(2), pp. 439–473. doi: 10.5194/hessd-4-439-2007.
- Pourel, D., 2017. *Multi-criteria optimization for better indoor environment in UK homes*. M.SC, University of Westminster
- PSI: Policy studies institute (2016) Available at: <http://www.psi.org.uk/> (Accessed: 19 December 2016).
- Littlefair, P. (2011). *Site layout planning for daylight and sunlight: a guide to good practice*. IHS BRE Press.
- Nicol, J.F., M. Humphreys, S. Roaf (2012). *Adaptive Thermal Comfort*. Routledge.
- Olgay, V. and A. Olgay (1963). *Design with Climate. Bioclimatic approach to architectural regionalism*. Princeton, Princeton University Press.
- Overheating in dwellings: BRE Trust, Watford
- Zero Carbon Hub (2012), *Understanding overheating, where to start*, NHBC foundation, London

# Towards a typology of listening: The balcony as a sonic interface in evolution

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## Abstract

This paper is an opening towards a comprehensive typology of listening that corresponds to the emerging forms of residential building interfaces. We shall focus on Balconies as a main study object of the current research. In fact, ecological approaches in designing residential buildings (Concerto, HQE, eco-districts) produce highly developed architectural typologies of building facades under the form of double skin, deep balconies, large loggia, covered or semi covered terraces, that should be analysed as such.

The main corpus on which this paper relies on is the research project *Esquis'Sons!* on « sustainable soundscapes » conducted by Cresson research center - ENSAG. The project is about studying the sound qualities of intermediate spaces located on the building facades such as the Balconies, Loggias, Terraces and Corridors (BLTC). The project's main objective is to elaborate a **catalogue of remarkable listening situations** of these interfaces through crossing the physical form, sensory phenomena and social practices. Based on this database, the current article overall aim to elaborate a **typology of listening situations** that categorizes in homogenous types the new forms of sound composition corresponding to new architectural vocabulary that building facades affords.

Focusing mainly on three sustainable districts in France: Vigny-Musset, Caserne de Bonne and Trapèze-Ile-Seguine, the elaborated methodological protocol put together a collage of methods in situ and in vitro that are systematically applied to each BLTC: sound recording up to 10 minutes, acoustic measurements, architectural sketches with accurate dimensions, in addition to short interviews with the inhabitants. This typology shall strengthen the sound culture of space designers whether architects or urban designers by showing the spatial and sound variations on both urban and architectural scales.

**Keywords:** sonic ambience, balcony, facades, typology, eco-district, sound affordance, interface

## Building interfaces, Sustainable soundscape, urban densification

We are interested in a miniature space *i.e.* the balcony, considered an important architectural element of the habitat that provides a unique experience to the inhabitants. Defined as a platform that access the exterior, the balcony is a private space suspended above the public and collective realm. It marks several thresholds separating the interior and the exterior, the private and public, the individual and collective spaces. This is why it has the status of an intermediate or in-between space. It is worth mentioning that the balcony is a generic term that refers to other forms of opening such as loggias, terraces and corridors (BLTC).

The keen interest in this space is due to the fact that it introduces a new architectural vocabulary that has been developed in the so-called Eco-districts. We have chosen a sonic approach for studying this architectural element that seeks to evaluate their potentials from a sound point of view in different urban and climatic contexts in Europe.

For elaborating a new typology of listening, the main database on which this article is derived from is the research project: *“Esquis'Sons! Tools to design sustainable sound environments”*. This project was conducted to respond to a French national call for project

on the theme « sustainable urbanism and sound environment» launched and funded by the ADEME - *Agence de l'environnement et de la maîtrise de l'énergie*. The project is carried out by Cresson research center on sonic space and urban environment, Grenoble School of architecture - France<sup>1</sup>.

In fact, the logic of sustainability favours new models of urban development and new forms of densification for limiting urban sprawl. In this optic, many municipalities at different scales build sustainable neighbourhoods labelled as eco-districts. These are considered as laboratories of experimentation or levers to build future sustainable cities.

In order to encourage inhabitants to live in dense urban context and accept the idea of collective housing, it is necessary to propose extensions to the outside offering various potentialities of use: deep balconies, wide terraces, patios, courtyards, shared gardens, etc. These are spaces that negotiate their intimacy with public spaces due to their new forms and their emerging social practices.

How to create new extensions attached to the apartment honored with spatial, climatic and sound qualities? Indeed, the lived experience in the balcony depends not only how inhabitants invest this space, but also on the potentiality of the constructed space (dimensions, materials, privacy, degree of exposure to public life) and the sound qualities of the street on which oriented this balcony. Reciprocally, the street receives the sonic events produced in the balconies.

The project *Esquis'Sons!* relates two main dimensions: on the one hand, the density as an important characteristic towards sustainability and, on the other hand, the social acceptance of densification. In this context, *Esquis'Sons* develops two hypotheses: the first one stipulates that inhabitants, to whom the "ideal residency is a private house with garden" i.e. the American dream, could accept more easily the density if the apartments propose extensions to the exterior spaces. The amelioration of the sound qualities of the BLTC will reinforce the social acceptability and may encourage people to live in dense urban context. The second hypothesis concerns the ability of these BLTCs in offering "variable uses" and opens multiple potentials to new categories of use due to a particular "*sound affordance*"<sup>2</sup> referring to the different potentials of use that the sound space permits (Augoyard, 1978).

From an operational point of view, the interest in the balcony as an architectural element, makes it possible to switch the reflection on sustainability from the scale of urban morphology and the development of a district, to an architectural scale which is that of the human body in motion (Chelkoff G. et al., 2003), a scale at which perceptions and representations of the environment are constructed in the ordinary actions of everyday life (Augoyard, 1978).

The research project – *Esquis'Sons* explores in 6 sustainable districts in Europe Germany (Französisches Viertel – Tübingen), Spain (Ecociudad – Sarriena), France (Vigny-Musset, Caserne de Bonne, Trapèze Ile Seguin) and Sweden (Hammarby Sjöstad - Stockholm)

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<sup>1</sup> The Cresson research team was multidisciplinary composed of acoustician, **Nicolas Rémy**, as a scientific coordinator and the PI of the project, he is assistant professor at Volos School of architecture: Greece; **Grégoire Chelkoff**, architect and professor at Grenoble School of architecture: France, as the second scientific director of the research. **Jean-Luc Bardyn**, sound technician; **Noha Gamal Said**, architect and urban designer, assistant prof. at Ain Shams School of architecture and a researcher at Cresson- ENSA Grenoble; **Theo Marchal**, Architect DPLG, Assistant lecturer at ENSA Grenoble, PhD student at Cresson – AAU: ENSA Grenoble. **Hengameh Pirhosseinloo**: Architect DPLG, PhD student at Cresson- AAU: ENSA Grenoble.

<sup>2</sup> The theory of « affordances » by J. J. Gibson (1979).

the sound qualities of intermediate spaces located on the building facades. These sites were chosen due to their capability of affording remarkable and innovative architectural forms of BLTC and underlining the morphological evolution of this typology of spaces. For assuring a variety of urban morphology, the different eco-districts are chosen along a north-south axis in Europe that crosses different cultural, climatic and urban contexts. Different criteria have been established to choose the case-studies:

The chosen 6 case-studies are meant to fulfil the following criteria which appeared to us fundamental and allowing a cross analysis.

- The sites should be recent enough - constructed after 2000 – in order to propose an interesting architectural typology of BLTC in terms of forms, materialities, composition of facades.

- These BLTCs must have belonged to classic and innovative urban forms, particularly in terms of environmental management, noise, gender diversity or program.

- it is necessary that the appartements should be delivered since few years so that users have sufficient time span to be settled and to develop their proper usage pattern.

- Finally, we also avoided the well-known eco-districts, because residents are often tired of answering questions for investigators, and this would certainly have caused problems to access housing.

It is important to present the set of methods that has been progressively applied both *in-situ* and *in-vitro* for elaborating the catalogue of remarkable listening situations.

**Observation in-situ:** the first investigation of the different sites. This phase has led to spot 72 balconies with most innovative architectural forms or usage patterns;

**In-situ sound recordings** in each balcony. For understanding the difference in listening and the impact of the spatial configuration on architectural and urban scales on the sonic ambience, several sound recordings have been conducted in each balcony, each soundtrack lasts for 10 mn. The different positions of the micro were chosen with the inhabitants in order to correspond to the real and recurrent use of the balcony: standing and sitting positions, in front of the handrail or near the facade. This phase is accompanied by architectural sketches with accurate dimensions in addition to short interviews with the inhabitants for understanding their usage pattern.

**Multiple sessions of collective listening:** For understanding the specificity of each listening situation, inter-team collective listening sessions have been organized to exchange how each researcher perceives each soundtrack. The sound perception covers both the ambience of the balcony and the surrounding soundscape to which the balcony is exposed.

**Urban section as a representation tool:** the interest in urban section lies in its capacity to: show the topography of the site, building heights, as it integrates the vertical dimension; Localize the sound in its urban context; Illustrate the urban morphology and the behaviour of the sound propagation; Show the urban voids, their uses and their materials, and how they affect the soundscape of the street; visualize the sound interactions between public spaces and private spaces and the buildings' interfaces (Fig.1).

In Esquis'Sons research, 72 remarkable listening situations have been identified in the 6 districts. As we are privileging a sound approach, we called for the methodological analysis that layers the architectural form "*forms*", sound experience "*formers*" and space use "*formalities*", developed by Grégoire Chelkoff (Chelkoff, 2009). Based on this triad, we have developed descriptive sheets that detail the sound characteristics of each listening situation.

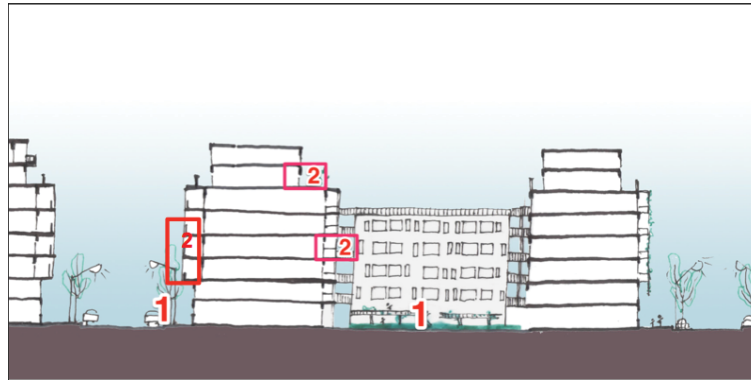


Fig. 1: Urban section & position of balconies under study

### Three representative eco-districts in France

In this context, we have chosen three ecodistricts: **Caserne de Bonne, Grenoble, France (CB)**: The ZAC (joint development zone) de Bonne is located in the city center of Grenoble on a former military compound. The new housing units are located in the south of the district, with various and innovative types of BLTC on the facades. The urban morphology is based on reviving the idea of courtyards (A, B, G, H, J and N). The islands are surrounded by three buildings forming a U-shape with a shared central garden (Fig. 2 to the left) .

**Vigny-Musset, Grenoble, France (VM)**: The ZAC Vigny-Musset is a large-scale operation initiated by the municipality of Grenoble in the south of the city during 1990s. Following a contemporary urban design with its closed and semi-open islands formed by a central square green spaces. The district has a strong presence of interfaces such as balcony, terrace or loggia (Fig.2 in the middle).

**Trapeze of Île-Seguin, Boulogne-Billancourt, Hauts-de-Seine, France (TIS)**: It is a renovation project on a former Renault factories in Boulogne-Billancourt for constructing a new mixed-use district with a considerable balance between dwellings, offices and green spaces. The housing design presents a remarkable typology of balconies, terraces, loggias and double skin façades. (Fig.2 to the right).



Fig. 2 The urban morphology of the three eco-districts: Caserne de Bonne to the left, Vigny Musset in the middle, and Trapezè Ile Seguin to the right.

## Comparative analysis methodology

In the current paper, we have limited our analysis to 30 remarkable listening situations corresponding to three eco-districts in France. The elaboration of a typology of listening is about comparing the different listening situations between them and categorizing them into homogenous *types* that put the listener in similar sonic situation. Each type of listening may gather balconies with different spatial configurations, different emplacement on the facade and looking over different urban contexts.

The main methodology of this article is to conduct *a comparative analysis* in two phases: the preliminary phase consists of a **lexical research** in which we have developed a cross-analysis study using the official website of the project *Esquis'Sons!*<sup>3</sup>. In this step, we have traced the *recurrency* of certain keywords referring to a specific listening situation for example: acoustic recession or exposure. The apparition of the keyword in the descriptive sheet, may be in the title, the general description of the sonic ambience, or in the form or the way we listen the space, or even in space occupation.

The subsequent phase is more comprehensive and demands a clear understanding of the different *conditions of the ambiances* that help producing each sound situation. It crosses different fundamental layers of database: *architectural form, visual perception, sound perception, temporal and cultural dimensions and usage patterns*. This phase helped deciding for each listening situation the proper category or type to which it belongs.

## The balcony: an architectural element in evolution

The first step towards elaborating a typology of listening is to list the different spatial configurations and to highlight the different emerging forms of interfaces that took place since the beginning of the 21<sup>st</sup> century. The spotted balconies can belong to recognized forms of balconies: such as balconies, loggias, terraces, and corridors (BLTCs), or, on the contrary prove a *metis form* of two or three main typology of form. Despite being well-known architectural expressions, it is important in our context to highlight the difference between them:

A **balcony** is defined as: *a balustraded or railed elevated platform projecting from the wall of a building*. The different definitions of balconies highlight its projectile aspect as a body projected or impelled forward.

A **loggia**, is defined as: *"a gallery or arcade open to the air on at least one side" or "as a space within the body of a building but open to the air on one side, serving as an open-air room or as an entrance porch"*. It is an enclosed space that is encased or embedded in the building façade.

A **terrace** is "an open, often paved area connected to a house or an apartment house and serving as an outdoor living area; deck"; "the top of a construction, used as a platform, garden, etc. "; or "a flat roof of a house"; "an open platform, as projecting from the outside wall of an apartment; a large balcony". The terrace represents the sense of a *platform*, i.e. an advance of a building settled on a structure and uncovered to the sky. It is more related to the ground floor or the roof with large dimensions when compared to the balcony.

A **corridor**, *coursive* in French, *"is a gallery or passage connecting different parts of a building; hallway. It might be external or internal"* or *"a passage into which several rooms or*

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<sup>3</sup> <http://www.esquissons.fr/analyse-croisee.html>



*apartments open*". The corridor points out an intermediate linear space that permits accessing to the apartment.

### **Metis forms of balconies**

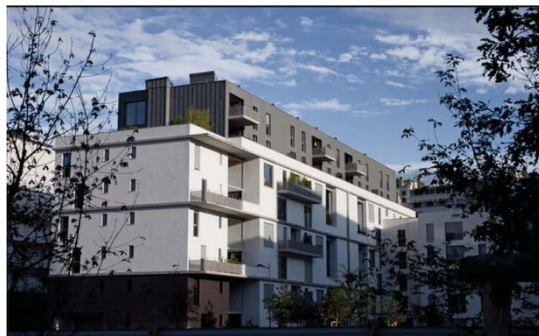
It is important to highlight the new emerging forms of balconies that define the design of interfaces in eco-districts. By the form metis we mean a hybridization of two, three or more forms of that above-mentioned standard categories (BLTC). In fact, the primary exploration of the site helped spotting different metis forms of interfaces for example:

**Loggia-terrace:** it is a terrace which part of it is covered form both sides and the ceiling while another part is open laterally and vertically to the sky.

**Double skin-loggia:** it is a loggia located in a double-skin façade. Providing the ability to open or close the secondary façade, this form offers to space users the choice between exposure and protection.

Other forms of balconies are more complex that combine three or four categories.

**Hybrid form of balcony:** It combines more than two categories and they become more complex: we can refer to an interface in Caserne de Bonne, Grenoble, France. The balcony is part of a duplex apartment. The double-height loggia gives the impression of being in a terrace more that a loggia. In addition, the balcony can be protected from the sun by roller blinds that give it the balcony a sense of double skin. In addition, other part of the interface takes the form of balcony (Fig. 3).



Hybrid Balcony (CDB)



Long corridor for bicycles (VM)



Balcony-court (TIS)



Fig. 3: Metis and innovative forms of balcony in the three districts.

## Towards a typology of listening

A typology of listening aims at identifying and categorizing the different ways of hearing, being heard and the way one perceives the sonic ambiances of the balcony. It is about identifying several types of sound situations that put the listener in a particular ambiente conditions. A typology crosses several criteria that are embeded in the above-mentioned three dimensions: the form of the balcony, its location on the facade, the surrounding urban configurations, the perception of the listener, the usage pattern and finally the temporal dimension. The elaboration of this typology is based a *sono-spatial* entry that crosses three dimensions:

- **Architectural form:** in which we studies in detail the dimensions, materials, spatial configurations of each balcony. The architectural form is represented in detailed plans and sections;
- **Visual perception:** based on the position of the balcony on the façade we study the visual study that relates the balcony to the surrounding urban environment ex. visual opening, height, relation to street, degree of exposure. Visual perception is presented in urban section that shows the relation between the balcony and the urban context.
- **Sound perception:** this understanding of sound crosses some acoustic characteristics of the balcony and the surrounding environment that include certain objective acoustic measurements such as *Leq*, *Impulse response*, *space reverberation* and that different sources of sounds, their way of propagation in the space. This database includes both architectural and urban scales. It includes

The listening typology underlines *the specific conditions of sonic ambiances* that each interface offers. In other terms, this phase is about understanding the *sound affordance* of each balcony. From the understudy sample of 30 balconies, nine **types of listening** have emerged: between **sonic exposure** which involves a confrontation or an immersion in the sound environment, the **acoustic recession** which, on the contrary, allows a partial escape, the **double listening** which gives the choice to space user to alternate listening between the interior and the exterior, **panoramic soundscape listening**, the **cocoon** linked to a nesting effect accompanied by a sensation of interiority, **reverberation** related to the use of reverberant materials or a specific urban configurations, **sound screen** related to the effect of filtration, **sonic cascade** phenomenon associated to a displacement of balconies positions on the façades where the listener is capable of hyperlocalizing the sound sources, **metabolism** corresponding to the effect of *metabole* that refers to a form of dynamic stability of the sound climate.

In the following part we shall detail two types of listening related to balconies: sonic cascade and double listening. We have developped those which seemed to us the most relevant types that introduce new listening modalities of balconies.

It is worth mentioning that it is possible that balconies with varied forms, facing different exterior environments or initiating different space use or even belong to the same listening type. On the contrary, balconies that belong to the same architectural typology may correspond to different types of listening. In addition, a balcony may blend several types of listening together (Fig. 4).

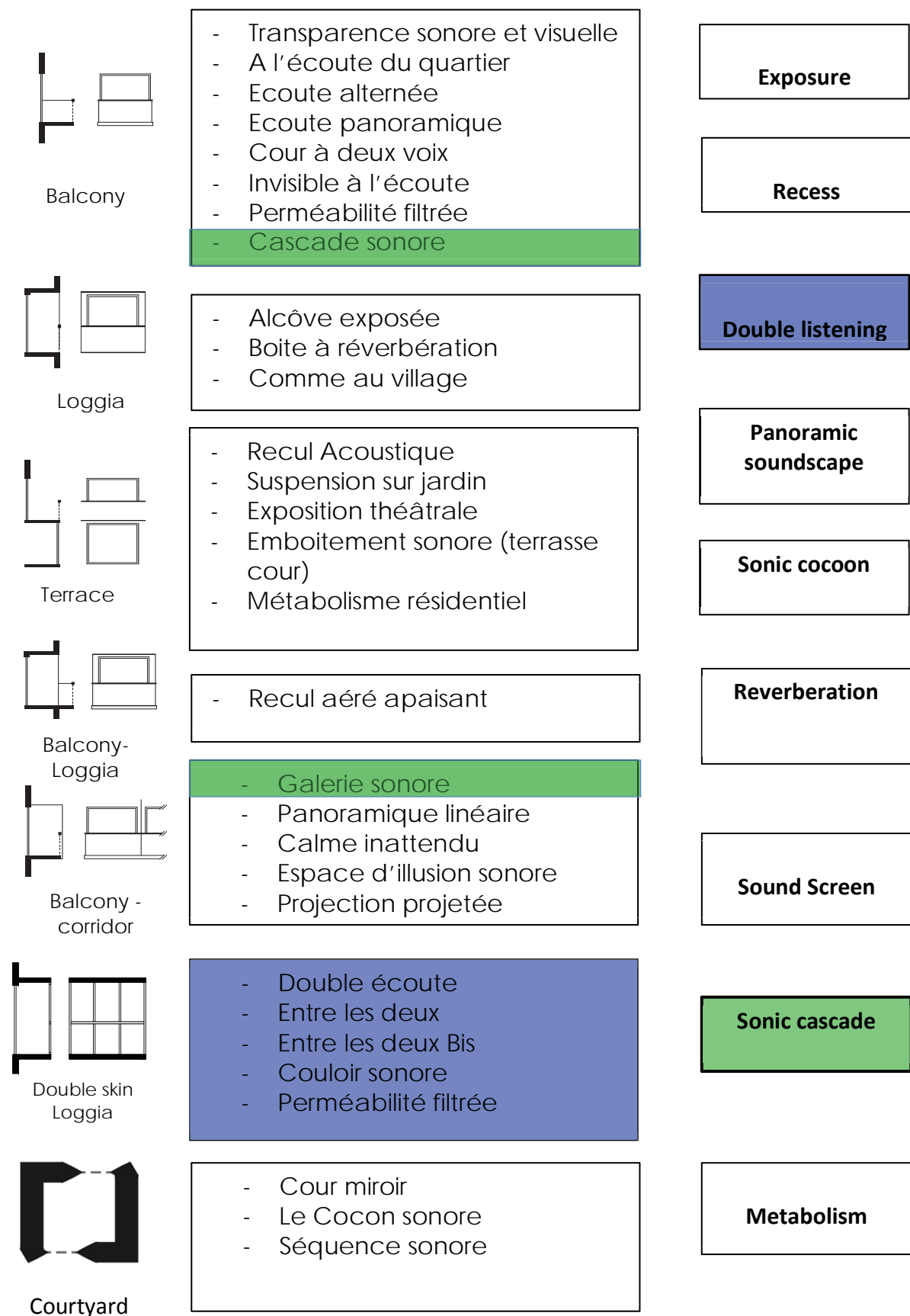


Fig. 4: The different architectural forms of BLTCs to the left, that develops remarkable listening situations (in the middle) that corresponds to the different Types of listening (the column to the right).

### ***Sonic Cascade (Le cascade sonore)***

The term cascade is defined in the dictionaries as the succession of waterfalls. It attributes what happens in an irregular rhythm. The cascade as a type of listening involves a change in the vertical level defining a descent and a rise of sound. The produced sound space is characterized by the hyper localization of many sonic sources coming from the surrounding balconies: top, bottom, on both sides, opposite side...). The composition of sounds is both spatial and temporal because the minor presence of any sound source impacts the listening; sounds can appear and disappear in time and the sonic ambience can be more animated or more calm according in different times along the day.

### ***Urban and architectural conditions that modulate the sound cascade***

This mode of listening is more dependent on the spatial organization of several balconies, the *overlap* between the balconies of the different floors does not create continuous sound bands but rather sound fragments dispersed in the space. The depth of the balconies is also an important factor, as the sum of balconies constitutes a vertical layer added to the façade creating therefore a sort a *micro-ambience* where sounds displace and reverberate in the space. This type of listening has been detected in an innovative form of corridor of a residential building located in Caserne de Bonne – Grenoble, France and designed by Edouard François. It is an exterior wooden structure that leads to a very particular form of balconis shaped as private passages leading to the main entrances of the apartments. The different balconies are staggered along the façade as shown in Fig. 2.

The whole structure constitutes an intermediate space between the building and the street. The sound space represents a cascade due to the overlapping form of both corridors and balconies. The partial coverage by the floor of the balconies at the top reinforces the visual and sound exposure of the balconies. This interconnection creates a network of identifiable sound sources that corresponds to the hyperlocalization sonic effect.

The innovative architectural form is phonically animated at certain moments of the day due to the different emerging uses: it is a space of short encounters, a place where people can eat on their balconies, work or socialize. In terms of sonic ambiances, this architectural element revives the image of a Mediterranean street (Fig. 3 &4). The sonic cascade as a type of listening has been spotted in another urban context with completely different architectural configurations. The building is located in Vigny-Musset, the interface under study is a balcony organised in a staggered form on the façade. The intimacy of the space in front of the interface puts the listener in more or less the same sonic ambience (Fig.4).

### ***Double-Listening***

The double-listening used in the field of marketing. It is a device that allows the supervisor of a call center to listen to the incoming or outgoing interviews of the operators. It is a monitoring and training tool. However, we shall use this term in order to highlight a very specific type of listening that gives different signification when compared to the above-mentioned well-known use. In terms of sound, the situation of double listening offers to space users the ability to *choose* between two sonic ambiances: exposure to the sound atmospheres of the public space, or, on the contrary, oriented towards the interior ambience i.e. be exposed to the sound space of the apartment itself and to the neighboring balconies. The latter situation imposes a situation in which neighbours share their intimacy.





<http://www.edouardfrancois.com/projets/logements/details/article/167/coming-out/#.WdG9PIzPHVo>

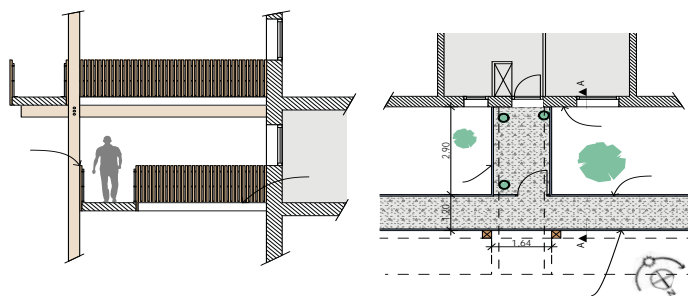


Figure 3: The external corridor of the residential building in Caserne de Bonne – Grenoble, France. Urban section and architectural drawings representing the corridor and the balcony. Caserne de Bonne - Grenoble, France. Designed by Edouard François.

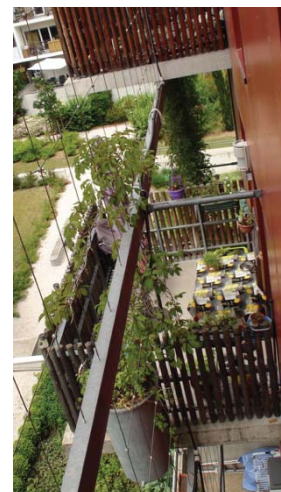


Figure 4: Residential building with staggered balconies on the façade. Vigny-Musset- Grenoble, France.

### ***Urban and architectural conditions that modulate double listening***

Double-listening occurs in most cases in double-skin loggias. This interface constitutes a buffer space between two layers of façades: the outer layer (secondary façade) which can

be fixed or modulated; the inner one (primary façade) which delimits the different interior spaces of the apartment.

The materials and the shape of the outer skin and their degree of porosity, for example dynamique and responsive skin made of wood, glass or metal. Another important architectural element that may have an important impact on forming the sound space is the separating walls between the different balconies. It impacts, by their height, their thickness and their materials, the sound insulation between the neighboring interfaces.

It is worth underlining the important sound affordance of this type of balconies and their ability to offer a degree of exposure or protection not only phonically, but also visually, that the second façade afford. This is directly reflected on the usage pattern. In fact, during the observation phase, this type of interfaces give the most elevated potentiality in varying the space use of the loggia: Gym, painting workshop, space for reading, eating, etc.

Two sub categories of double-listening situations are identified during cross-analysis of BLTCs:

**Selective listening:** the interface offers a clear dual exposure due to a high degree of sound isolation of the second façade, for exemple double-glass walls. When windows are Open: the background sonic ambience is reverberated on the façade and become perceptible; the near sounds coming from the neighboring balconies are indistinct as being *masked* by the sounds coming from the outside. In situations when windows are closed: the background ambience disappears and all the lateral sounds coming from the neighbouring balconies on both sides become identifiable and submerge the sound space of loggia. This subcategory corresponds to a double-skins loggia, located on the 4th floor in Caserne de Bonne (Fig. 5).

This type of listening is related to the existence of a moddable interface. Unlike its definition as being an important process of articulation between spaces and locations and its ability to punctuate movement from one ambience to another.

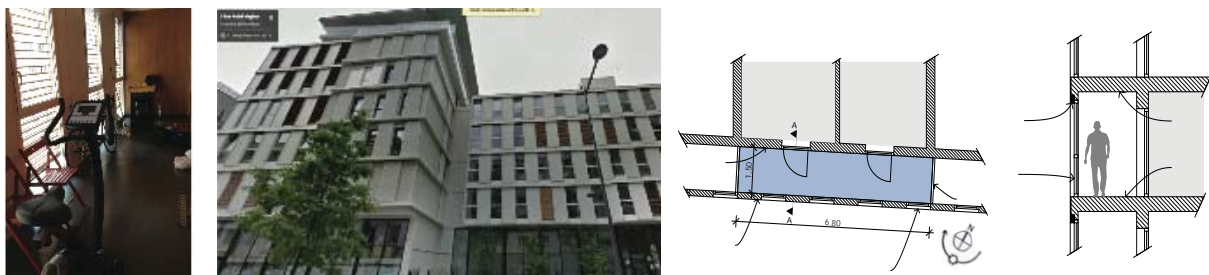
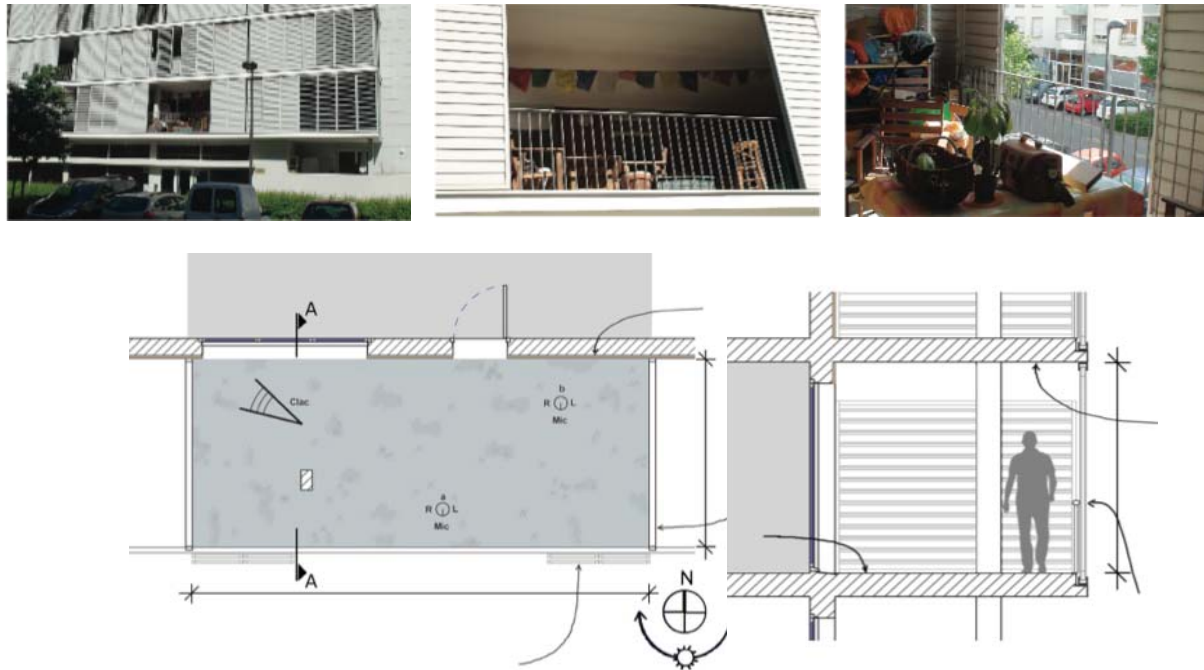


Figure 5: Residential building with double skin on the façade. Caserne de Bonne- Grenoble, France.

**Amplifier sonorous corridor:** The loggia can be closed completely by shutters. The partition wall wall does not reach the ceiling. When balconies exist along the façade, the empty space between the ceiling and the dividing walls allows sounds to propagate freely between the different balconies, creating a particular sound phenomenon, i.e. "*sonorous corridor*". As soon as the shutters are closed, one hears the presence of neighbors highly reverberated in the loggias of the same floor. The sound space is shared among neighbours of the same floor. This situation corresponds to a double-skins loggia located on the first floor in Vigny-Musset (Fig. 6).





## Discussion

The purpose of our work was not to evaluate the sound qualities of all identified balconies along the year (summer, autumn, winter and spring) or even along the day (morning, afternoon and evening), but to be present on the sites when they are phonically animated, that is to say:

- at the end of spring and during the summer,
- when balconies are occupied (to avoid the summer holidays),
- at the hours of the day when the ambiance is more animated by the presence of people: dinner time, getting out of schools, weekends, etc.

Despite that fact that our objective was to observe them in their current mode of operation or their ordinary situation, but we remained attentive to exceptional situations: Summer Festival, Music Festival, neighborhood parties, football matches, etc. Although These events are not representative to the ordinary experience of the neighborhood, it was interesting to study them due to the density and the intensity of the sound phenomena often associated with these events. These particular moments may reveal other phonic features of the neighborhood: the sound transparency of the district i.e. its capacity to receive distant sounds, presence of social groups animating public spaces, intensive uses of the public facilities, a particular type of sociability, etc.

## Conclusion

Contemporary eco-districts show more than ever a dynamic and rapid evolution that affects the production of intermediate spaces and their usage pattern. In fact, The spotted balconies or BLTC provide a new architectural vocabulary to design balconies that reinforce the quality of life in dense urban context. This architectural evolution results in emerging listening situations and developing new situations of listening to the city.

This article is an opening towards a typology of listening situations associated to the new forms of residential building interfaces. By studying the sound qualities of the intermediate spaces located on residential facades in these three sustainable districts in France and by making a comparative study between several new spatial and ambient configurations. Nine types of listening have emerged in this study that has been influenced, modulated and impacted by these new architectural forms. The above-mentioned types of listening can be enlarged and applied in the other districts in Europe.

A cross analysis study based on the triology (architectural form, visual perception and sound perception), allows to describe the minimum conditions of existence of these new types of listening situations. The importance of elaborating this typology is build up and strengthen a sound culture for city designer and developers through relating the spatial and sound variables on both urban and architectural scale.

If we are limited in this article to detail two types of listening: the sonic cascade and the double-listening, the rest of this typology will be developed in further research work.

## References

- Augoyard, J.-F. (1978). *Les Pratiques d'habiter à travers les phénomènes sonores – Contribution à une critique de l'habitat*. Grenoble : CRESSON
- Augoyard, J.-F. ; Torgue. H. (2005). *Sonic experience : A guide to everyday sounds*. Translated by McCartney, A. ; Paquette, D. McGill-Queen's University Press.
- BALAÏ O. ; CHELKOFF G. (1985). *La Dimension sonore d'un quartier*. Grenoble : CRESSON.
- CHELKOFF G. (2001). Formes, formants et formalités : Catégories d'analyse de l'environnement urbain in : *L'Espace urbain en méthodes*. Marseille : Parenthèses, pp. 101-124.
- Eleb, M. ; Simon, Ph. (2013). *Logement contemporain : Entre confort, désir et normes 1995-2010*. Ed. Essai.
- Rémy, N. ; Chelkoff G. (Responsibles Scientifiques). (2016). *Esquis'Sons! Outils d'aide à la conception d'environnements sonores durables*. Grenoble: Cresson. Rapport de recherche no. 88
- Rémy, N. ; Chelkoff, G. ; Marchal, T. ; Gamal Saïd, N. ; Pirhosseinloo, H. ; Bardyn, J.\_L. (2016). *Esquis'Sons ! Outils d'aide à la conception d'environnements sonores durables*. In : Nicolas Rémy (dir.) ; Nicolas Tixier (dir.). *Ambiances, tomorrow*. Proceedings of 3rd International Congress on Ambiances. Septembre 2016, Volos, Greece, Sep 2016, Volos, Grèce. International Network Ambiances ; University of Thessaly, vol. 1, p. 529 - 534,  
<http://www.esquissons.fr/>

# Thermal Comfort and Behaviour Control in Mixed-mode Office Buildings in Harbin, China

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**Abstract:** This paper presents findings from a two-week longitudinal case study of occupant thermal comfort and related behaviour control in offices in Harbin, northeast China. Long-time data were collected from on-line questionnaire surveys and data logger measurements of the thermal environment and occupant behaviour in the summer of 2017. A total of three mixed-mode buildings with four different types of office rooms and their occupants were selected. Behaviour was examined against both environmental and personal thermal comfort variables. Results indicated that thermal feelings and behaviour control differed with the type of office space. The three most commonly used methods for achieving better thermal comfort in summer were to open or close windows, switch on fans and switch on air-conditioning. The results show that the window control behaviour was always accompanied by the use of a fan or air conditioning. The results also show the influence of different variables on occupant behaviour, including environmental variables, personal factors and the geometry of the office rooms. Furthermore, the results from this study may provide a useful reference when designing and managing a better thermal environment for office buildings in northeast China.

**Keywords:** thermal comfort, behaviour control, office building, mixed-mode office

## Introduction

Investigating the interaction between occupants and their built environment has proved to be a meaningful way of evaluating building energy consumption and the quality of indoor building environments in recent years (Valentina and Rune, 2012; Hong and Lin, 2013). For commercial and residential buildings in the USA, the impact of human behaviour can account for 37% to 54% of the energy use (U.S Department of Energy, 2011). At the same time, changes in occupant behaviour will affect factors such as indoor air temperature and air flow, thus affecting their thermal comfort (Baker and Standeven, 1997). After the importance of occupant behaviour control was established, the mechanisms of interaction between behaviour control and buildings have now started to be explored.

Window opening behaviour is one of the most important thermal comfort adaptive behaviours. Haldi and Robinson (2009) developed and compared different modelling methods of window opening predictions by investigating fourteen offices. Yun and Steemers (2009) developed a time-dependent window opening behaviour model for building simulation, taking indoor air temperature and the previous window state into consideration. Heikel et al (2008) used monitoring data from a multi-occupant office and proved a strong correlation between opening windows, outdoor air temperatures and occupancy patterns. Prays et al (2011) found that the model of Haldi and Robinson stands out among several behaviour models, due to the support of a large dataset and their broad measuring

campaign. In recent years, data mining technology has been applied to the establishment of occupant behaviour models, so that the prediction of behaviour has made significant progress (Simona and Hong, 2014).

All this research has involved the collection of longitudinal data, which allows for the observation of occupant comfort and adaptive behaviour. Most of the current longitudinal surveys are only via data from loggers recording environmental physical parameters and behaviour state, but which do not track the occupants' thermal feelings. This is mainly due to the difficulty of conducting long-term questionnaire surveys. Much of the existing research focuses on naturally ventilated buildings, and less account is taken of buildings with air conditioning (AC) equipment. The reason for this is that the researchers believe that most adaptive behaviours, especially window opening behaviour, will not be produced in air-conditioned buildings. However, in practice, mixed-mode behaviour often occurs in AC buildings, accompanied by window opening behaviour.

According to the authors' surveys in office buildings, it was found that, regardless of whether or not the office room was natural ventilated, window opening behaviour was a very common type of adaptive behaviour. This research conducted a two-week survey of private and open space offices during a summer season in four mixed-mode office rooms in Harbin, a cold area of northern China. This research contributes findings based on this longitudinal survey of occupants' thermal feelings, behaviour control and environment variables. This paper seeks to study factors which have not been substantively covered by previous studies as below i.e.

- to contrast and explore differences in the indoor environment, occupant thermal feelings and adaptive behaviour of private and opening space offices rooms.
- to compare thermal sensation and adaptive behaviour in naturally ventilated and air-conditioned office buildings, accompanied by window opening behaviour.
- to examine long-term comfort and behavioural characteristics in mixed-mode office buildings located in the city in a hot summer period, which included naturally ventilated and air-conditioned types of rooms.
- to assess the influencing variables of adaptive behaviour for naturally ventilated office room in cold areas of China.

## **Method**

The summer survey was conducted in Harbin, north-east China, in July 2017. The survey included the assessment of occupants' sensation and behaviour using an online questionnaire survey and simultaneous measurement of indoor and outdoor environmental parameters from data loggers and a weather station. The survey was divided in to two periods; in the first week, the open plan office rooms had air conditioning (AC) switched on, and in the second week the AC was removed. Therefore, the surveyed office can be divided into three groups to make a comparison, and the details of this will be discussed in the comparison test sections. All participants had freely agreed to take part in the study

### ***Location and buildings***

The investigated office buildings are located at Harbin ( $125^{\circ} 42' -130^{\circ} 10' 3E, 44^{\circ} 04' - 46^{\circ} 40' N$ ), which is a typical cold city in China. Harbin is in the severe cold zone of China's building-climate zoning and experiences a medium - temperate continental monsoon climate, with four distinct seasons. The winter in Harbin is long and cold, while the summer

is short and hot. The short spring and autumn are transitional seasons with a quick changing temperature. From 1986 to 2015, the average minimum temperature in January was  $-22.7^{\circ}\text{C}$ , and the average maximum temperature in July was  $27.9^{\circ}\text{C}$ . Four office rooms in three mixed-mode buildings were selected and surveyed for two weeks in summer. Two of the rooms were private office rooms (one person) in building A and building B, and the other two (five persons) were open plan office rooms in building C. All the occupants in these rooms were invited as participants for the survey. The survey sites and conditions are shown in Fig.1 and Fig.2.

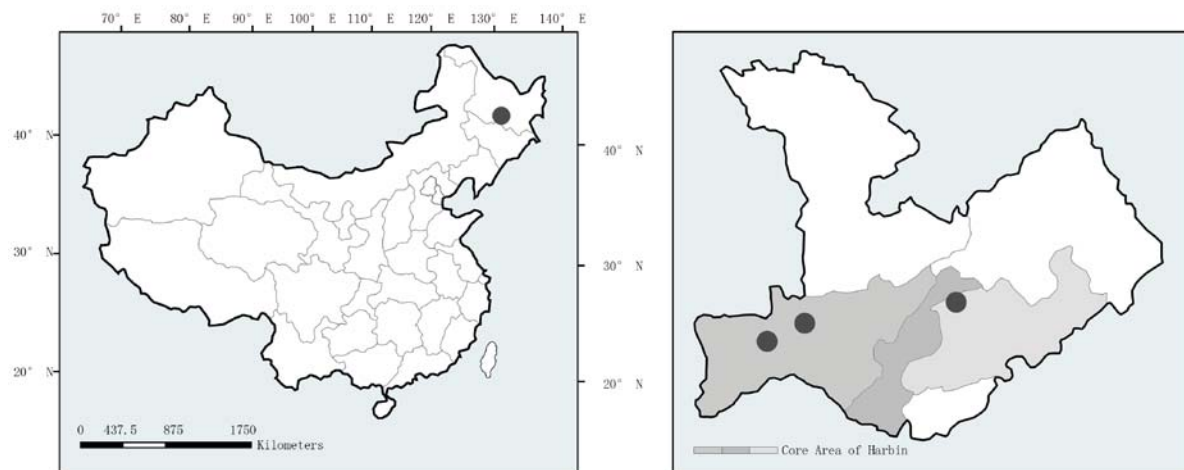


Figure 1. Location of Harbin in China (left) and geographical distribution of the surveyed offices in Harbin (right)

Following an assessment of field conditions in Harbin, the use of fans in office buildings was found to be very common during summer, but the use of AC was not, except for part of the open plan office buildings. Therefore, two types of mixed-mode buildings were considered in this research; one where one of the available behaviour controls was fan use with window opening, and the other was fan use and AC with window opening.



Figure 2. Offices orientation and offices types used in the survey.

### Comparative Test

In the first period of the survey, building C had AC in the rooms, and during the second time the AC was removed in both rooms (i.e. switched off). The geometric parameters and orientation of the two open plan rooms of the office building were the same. Therefore, this research had three groups of comparative tests. The first two were a contrast between



private and open plan rooms themselves. The third was between the two space types of naturally ventilated office rooms with fans. In this way, more physical variables changed during these two weeks and more data could be collected for analysing the behaviour controls influencing the parameters.

### ***Longitudinal survey and filed measurements***

Over the summer the subjects participated in a series of subjective and objective measurements of thermal comfort, behaviour control, and related items. These measurements were conducted by a three-part longitudinal survey as well as by environmental data loggers.

#### ***Longitudinal questionnaire survey***

The questionnaire of this study was a panel survey, a kind of longitudinal survey following the same subjects during a certain period of time. The surveys were organized using the questionnaire survey software Wenjuanxing and sent through the social application Wechat twice a day for ten work days. The data of people who were not in the office or did not stay indoors for more than 20 minutes were eliminated. There were 12 people attending the survey, with 182 effective responses. Each participant was given a certain code for marking when answering the questionnaire to make it easier to match the answers with the subjects. The survey included three parts - the start survey, the daily survey and the final survey. Opening with questions about personal characteristics, the start survey was a general questionnaire that asked subjects to recall their thermal feelings in their office rooms in each season and the past three months. The daily survey focused on the subject's feelings and the state of the window, fan and AC (open/closed/on/off) at the time they answered. The questionnaire was sent in the morning and afternoon time each day (there is a lunch break in every office in China) to give the subjects a routine of answering the questionnaire at the right time. For the final part of the survey, the main purpose was to know the occupant's overall thermal and relative feelings over the two weeks of the survey. The final survey also included an area where participants could provide their feedback about the accessibility, time expense, and general clarity of the daily survey instruments. Before the formal research, a weekly pilot test was conducted on office occupants from similar office environment. This helped inform small revisions to the daily survey, including the accessibility, clarity and response rate of the questionnaire. Table 1 shows the type of questions of these three parts of the survey.

#### ***Field measurements***

Alongside the longitudinal questionnaire data collection, continuous measurements of indoor and outdoor environmental parameters were recorded. The indoor air temperature and relative humidity were logged at 15 minutes intervals using HOBO U12-012 data loggers (accuracy:  $\pm 0.35^{\circ}\text{C}$ ,  $\pm 2.5\%$  relative humidity). Geometric design parameters of office buildings were also measured, including office room depth, width, window height and other parameters and were used to detect any relationship with window opening behaviour. The overview of the collection and integration of various data streams are shown in Fig.3.

#### ***Data analysis***

Changes of the occupants' thermal feelings, adaptive behaviour and environmental parameters were described in terms of the time-varying distributions. Point Biserial Correlation Coefficient ( $r_{pq}$ ) and Lambda/tau-y statistics were used to analyse the



correlations between each factor and adaptive behaviour.  $r_{pq}$  is a correlation measure of the strength of association between a continuous-level variable (ratio or interval data) and a binary variable (a scale with only two values). The Lambda Coefficient is suitable for two variables which have either a symmetrical or a non-symmetrical relationship. Its value may range from 0.0 to 1.0. Lambda provides an indication of the strength of the relationship between independent and dependent variables (IBM SPSS 2017).

Table 1. Structure and content of the longitudinal questionnaire

	Start Survey		Daily Survey (at the time of the survey)	Final Survey (for the overall two weeks survey)
Perceived Indoor Environment Parameters (7points)	Each season	Thermal sensation; Humidity feeling; Air movement;	Thermal sensation; Humidity feeling; Air movement; Smell; Outdoor noise; Temperature preference; Overall satisfaction	Thermal sensation; Humidity feeling; Air movement; Smell; Overall satisfaction
	Past 3 months	Overall satisfaction		
	Variables affecting window opening behaviour			
Status of the Office	-		Window	-
			Air conditioning	
			Fan	
Personal Information	Age; Gender; Time of living Harbin; Time of working in this office; Seat position		Clo	-
Others	-		Whether stayed in the office less than 20 minutes	Time expense
				Clarity of questions
				Method questionnaires distributed

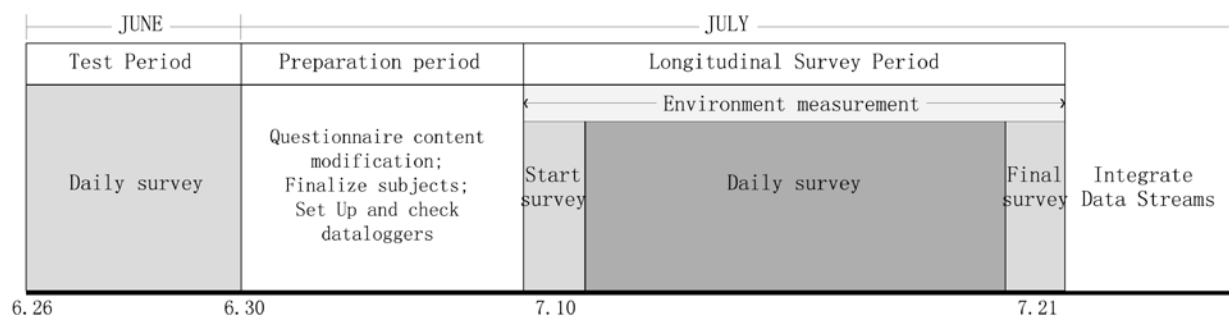


Figure 3. Collection and integration of survey, environmental data streams across two weeks.

## Results and analysis

The results from the survey are shown in Table 2. The analysis is ordered as the profile of participants, the environmental variables distribution, the comparison of thermal feelings and behaviours, including the correlation between parameters, and adaptive behaviours.

### **Sample size and Profile of participate**

Table 2 shows the sample size and the characteristics of the surveyed subjects. All the 12 occupants of the surveyed office rooms were invited to answer the questionnaire. The occupants' number in each room type is equal. When the subjects recalled their overall indoor thermal environment in the past three months, all the people chose the neutral one. After they finished the questionnaire and then recalled the two weeks summer overall feeling, more than half of the subjects changed their answer to dissatisfied, which might indicate the thermal environment has a negative impact on the occupants.

Table2. Subjects characteristics (Total N= 12)

	Category	N	% of final sample
Gender	Male	7	58.3%
	Female	5	41.7%
Office type	Private	2	16.7%
	Opening desk	10	83.3%
Recall of overall thermal satisfaction in April/May/June	= "Neutral"	12	100%
General overall thermal satisfaction during the survey	> "Neutral"	1	8.3%
	= "Neutral"	3	25%
	< "Neutral"	8	66.7%

The daily survey generated consistently high survey response rates ( $\geq 75.9\%$ ), yielding a total of 182 responses from the 12 subjects. The survey took just a few minutes to complete, and was positively evaluated by occupants. Table 3 summarizes key statistics regarding the performance of the daily survey during the two-week period.

### **Overview of Environment variables**

The overview of temperature and humidity changes is shown in Fig. 4, with the distribution of mean value as the daytime series. The vertical lines in these figures represent the boundaries of temperature and environmental changes throughout the survey period. The outdoor temperature of the second week is obvious lower than the first week. The AC was switched off in the second half of the survey in building C, which means that in first half of the survey building C was a mixed-mode office with AC and fan, while in the other days they can be regarded as naturally ventilated room with fan.

Table 3. Summary of daily survey performance across the summer survey run period

	Private Office	Opening Plan Office
No. of Response	31	151
No. Link Sent	40	200
Response Rate	77.5%	75.5%

Mean Time/Survey, Minutes	1.39	1.25
Clarity of the Questions <sup>a</sup>	1.5	1.375
Accessibility <sup>a</sup>	2.5	1.25
Overall Time Expense <sup>a</sup>	1.5	1.75
Each Questionnaire Time Expense <sup>a</sup>	1.5	1.75

<sup>a</sup> Mean response on scale, from -3 = very dissatisfied to +3 =very satisfied

During the survey period the mean indoor air temperature of each room was higher compared to the outdoor air temperature, which might be due to heat dissipation from the occupant and facilities. In the second survey stage, the outdoor temperature was lower, but the four rooms' air temperatures remained high. For the two rooms in building C, C1 only had a short time using AC, while C2 used AC during the whole first week. The mean indoor air temperatures for C2 room were obviously lower than for the other offices (because of the AC use). The average relative humidity (RH) of each indoor environment, with values between 40% to 80%, had a lower distribution than the outdoor relative humidity. This RH range would not influence thermal comfort feelings. The relative humidity of building C showed a higher trend compared with the private rooms in the second stage of the survey.

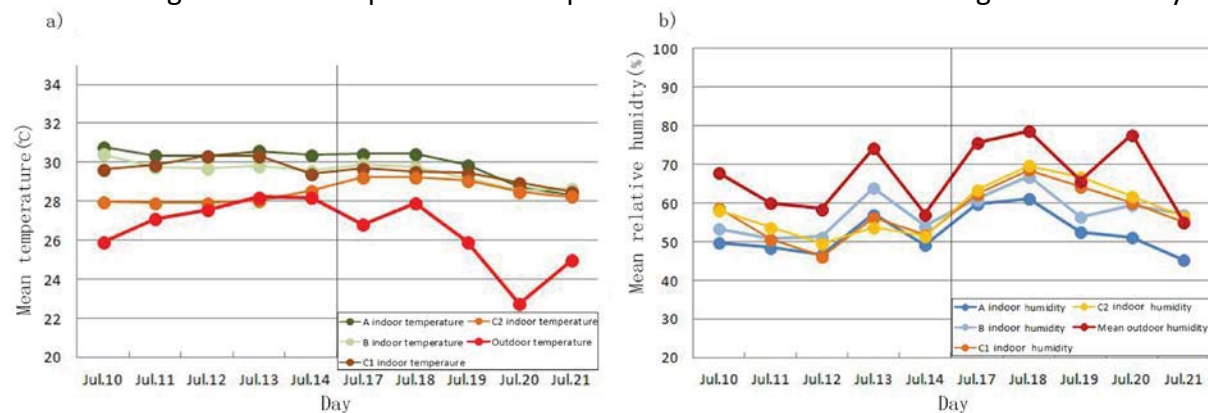


Figure 4. a) Mean daily value comparison of indoor and outdoor temperature. b) Mean daily value comparison of indoor and outdoor relative humidity.

### ***Thermal feelings and behaviour control***

The results of the occupants' indoor thermal feelings and adaptive behaviour were carried out by three comparison groups. The first two were self-contrast analysis of the private office and the opening space one, and the third comparison was between building A, B and C.

#### ***Results of group 1***

Fig. 5 compares the thermal sensation and satisfaction of two private office rooms. During the entire period, indoor air temperatures in rooms A and B maintained a stable level and kept a high value over 28°C. In the hot summer season, the fan was a necessity for a natural ventilated building. Room A used the fan, except in the morning of 13 July, while Room B used the fan across all the survey times. As can be seen from the statistics, in the summer the window opening behaviour was always accompanied by the fan being on. Both rooms kept the window open almost every day. All the parameters in the graph are the status of the indoor environment at the time the subjects were answering the questionnaire.

For thermal sensation, the occupants of the two rooms were both in a 'hot' state. The occupant of room B was in a stable state, while the one in room A was in a more fluctuating state. This may be because the user of room A was more sensitive to temperature and therefore did not feel hot in the morning. When the outdoor temperature was significantly

reduced, although the indoor temperature was only reduced by about 2°C, the occupants' thermal sensation was significantly reduced to around the neutral value. The degree of fluctuation of the overall thermal satisfaction corresponded to the thermal sensation from slightly dissatisfied to slightly satisfied during the survey period.

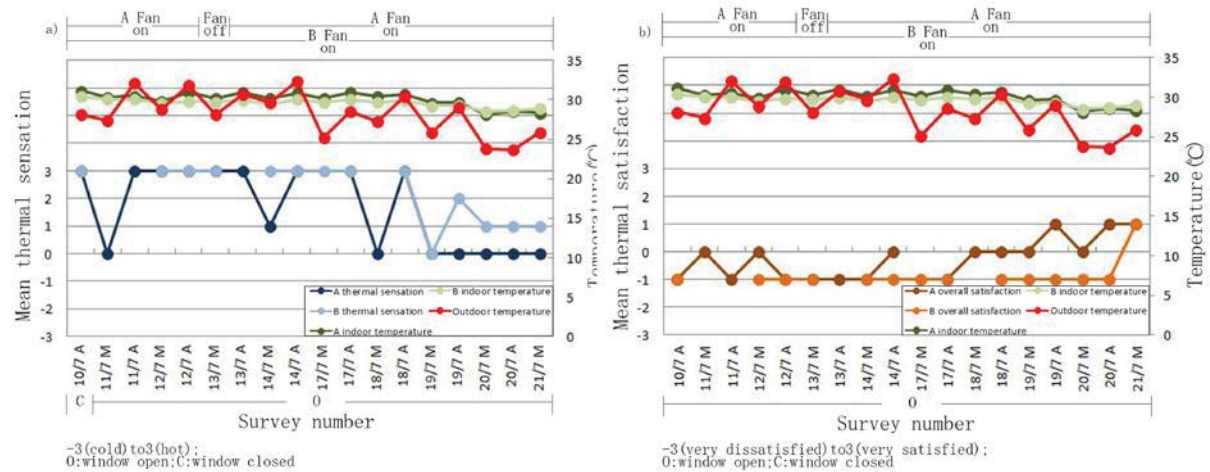


Figure 5. a) Mean value comparison of A and B thermal sensation. b) Mean value comparison of A and B thermal satisfaction.

### Results of group 2

Although Harbin belongs to a cold area in China, the summer is always very hot, and the extreme air temperatures can reach 39.6°C. In most cases, part of the large space office type or multi-person office used AC in Harbin. The rooms C1 and C2 (both open plan rooms), were subjected to a comparative experiment. The test was divided into two stages; in the first stage, the C building had AC equipment; in the second stage, the AC was removed.

For stage one, at the time of answering the questionnaire, the indoor and outdoor temperature of C1 maintained a high degree of consistency (Fig.6). In this period, C2 used AC almost every day, which led to an obvious lower indoor temperature. The occupants of C1 did not use the AC. As a result, the thermal sensation of C2 is lower and satisfaction higher than in C1, which had a neutral value.

For stage two, Fig. 6 shows the indoor air temperatures of the two rooms generally presented a similar distribution and higher temperatures than outdoors. After the AC was removed, the C building changed to a naturally ventilated building with the fan device. Occupants of building C showed similar behaviour modes of using the fan at the same time with the windows open as users of building A and B. C1 maintained a routine of opening the two window every day, while C2 kept one window open almost the entire week and another open for part of the time. The thermal sensation of rooms C1 and C2 showed a hot level and the satisfaction was very low, from dissatisfied to very dissatisfied.

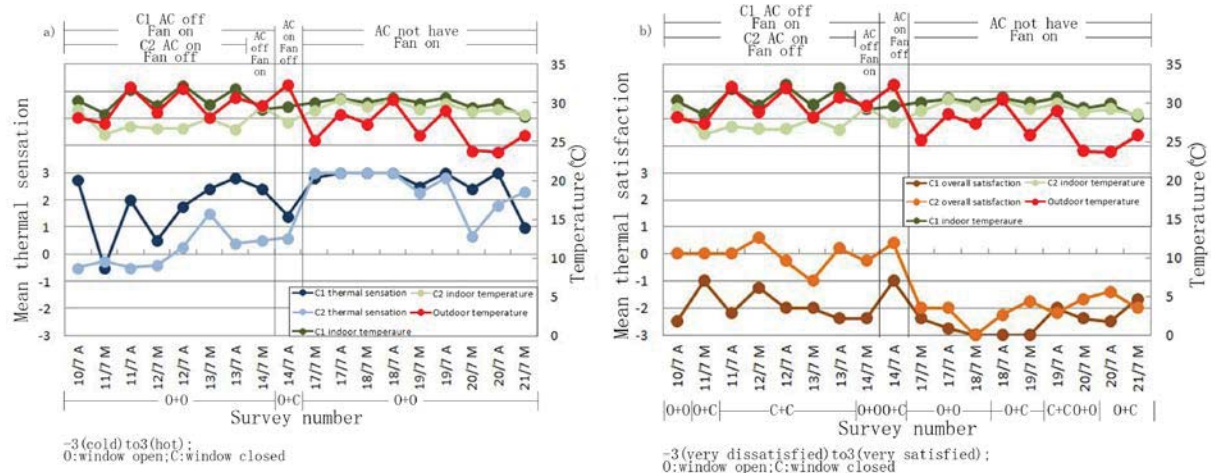


Figure 6. a) Mean value comparison of C1 and C2 thermal sensation. b) Mean value comparison of C1 and C2 thermal satisfaction.

### Results of group 3

Fig. 7 shows a comparison of buildings A, B and C in the second stage of the temperature, and all the indoor temperatures show a big difference, and were higher than the outdoor temperature. After the C building switched off the air conditioning, its indoor temperature gradually increased, to a little higher value than the private office.

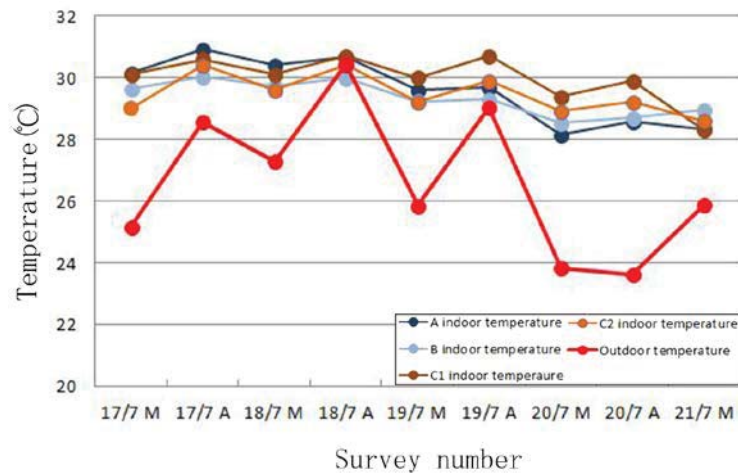


Figure 7. Comparison of indoor and outdoor temperature at the time of the questionnaire.

In this period, with the decrease of the outdoor temperature, the thermal feelings in the private office rooms showed a more substantial reduction than in the open space one, although the indoor temperature changed little. For thermal satisfaction, the data of all the research objects were all increased for the decrease of the indoor and outdoor temperatures. The overall thermal satisfaction of the private office was much higher than for the open space one.



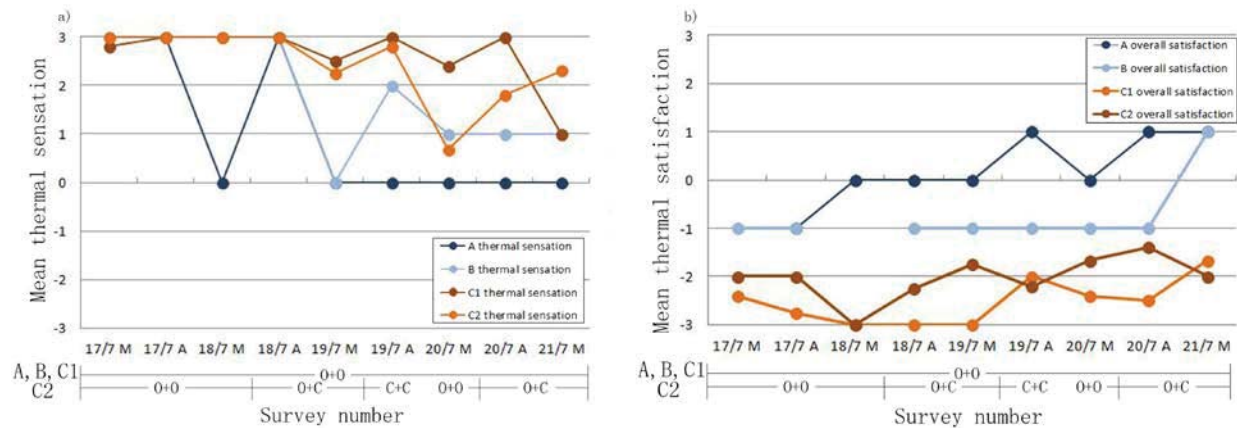


Figure 8. a) Mean value comparison of A, B and C thermal sensation. b) Mean value comparison of A, B and C thermal satisfaction.

### Correlation variables and window opening behaviour

The impact variables on the use of window and fan behaviour in naturally ventilated office were examined by Point Biserial Correlation Coefficient and Lambda/tau-y Coefficient. The correlation analysis of mixed-mode office rooms with the AC device cannot be computed in this research due to the limitation of the data amount.

In the hot summer season, occupants in the naturally ventilated office, in most cases, always chose to open the window while using the fan. From the questionnaire, some subjects wrote that they thought that if the window was closed, then the indoor environment would be much stuffier and hotter. Table 4 shows the physical parameters, occupant experience parameters, and subjects' personal characteristics had an impact on window opening behaviour. Among the physical environment parameters, only indoor humidity affected the window behaviour. This may be because, when the temperature reached a certain value, the window opening behaviour was much more related to humidity than the temperature changes. Many studies have found that the indoor and outdoor temperature are good parameters for predicting windowing behaviour. However, when only observing window opening behaviour and its influencing factors in summer in Harbin, it was found that the summer temperature fluctuation did not affect the window opening probability, while the indoor humidity and window behaviour had an obvious correlation.

Table 4. Impact variables on adaptive behaviour of naturally ventilated building

	Window Opening		Fan On	
Physical Parameters	Point Biserial Correlation Coefficient $r_{pq}$ and significance level $p$			
	$r_{pq}$	$p$	$r_{pq}$	$p$
Indoor Temperature	-	NS	0.375***	0.000
Outdoor Temperature	-	NS	0.225**	0.008
Indoor Humidity	0.274**	0.001	-0.35***	0.000
Thermal Feeling	Point Biserial Correlation Coefficient $r_{pq}$ and significance level $p$			
	$r_{pq}$	$p$	$r_{pq}$	$p$
Thermal Sensation	0.221**	0.009	-0.17*	0.047
Air Movement Feeling	-0.402***	0.000	0.424***	0.000
Smell	-0.302***	0.000	0.47***	0.000



Outdoor Noise	-0.298***	0.000	0.524***	0.000
Temperature Preference	-0.301***	0.000	0.194*	0.22
Thermal Satisfaction	-0.359***	0.000	0.483***	0.000
<b>Building Characteristics</b>	Point Biserial Correlation Coefficient $r_{pq}$ and significance level p			
	$r_{pq}$	p	$r_{pq}$	p
N of People	0.4***	0.000	-0.395***	0.000
Room Width	-	NS	-0.422***	0.000
Room Depth	0.348***	0.000	-0.576***	0.000
Floor Area	0.348***	0.000	-0.676***	0.000
Window Size	-	NS	-0.352***	0.000
<b>Other Parameters</b>	Lambda/tau-y Coefficient			
	Window opening(dependent)		Fan on (dependent)	
	value	p	value	p
Room Number	-	NS	0.69**	0.001
Room Type	0.172***	0.000	0.69**	0.001
Time of Survey	-	NS	-	NS
Gender	0.092***	0.000	-	NS
Fan	0.056**	0.006	-	NS
Window Opening	-	-	-	-

Notes:  $0.01 < p < 0.05$  is \*,  $0.001 < p < 0.01$  is \*\*,  $p < 0.001$  is \*\*\*

The feelings of the indoor environment had a certain impact on the window behaviour, including thermal sensation, air movement feeling, temperature preference and thermal satisfaction. For architectural design parameters, the office type, room depth and floor area all had an influence on window opening. Gender also showed a weak but discernible impact on window opening.

Indoor relative humidity and indoor thermal feelings both affected fan use. Simultaneously, room type and geometric design parameters of the building had a significant effect on fan use. However, unlike the window opening behaviour, both the indoor and outdoor temperature had an influence on fan use. Occupants of different genders did not show much difference in terms of using a fan. It is worth noting that these mixed-mode office rooms maintained a high degree of consistency of window opening behaviour, while the use of the fan varied among these rooms. Many studies have pointed out that window opening behaviour has a greater relationship with room arrival and departure. In this study, the time parameters represent only the morning and afternoon, and different times did show a great impact on window opening and fan use behaviour.

## Conclusion and discussion

This paper presents the results from a longitudinal survey to characterize occupants' thermal feelings and adaptive behaviour in three mixed-mode buildings in Harbin, a cold area of China. The results of this research are:

- When the outdoor air temperature decreased, the occupants' thermal sensation in the private office rooms was significantly reduced compared to the open plan office spaces.

Overall thermal satisfaction of private office occupants was much higher than the open plan office occupants.

- Occupants in AC office rooms might not choose to use the AC device in case of getting cold. In the mixed-mode office buildings with AC, thermal sensation and satisfaction changed with the indoor temperature. Comparing the window opening behaviour in the mixed-mode office with AC use and naturally ventilated office with fan, the former one shows a more volatile trend and the latter tended to have a more stable state.

- In the northern part of China, due to the hot temperatures in summer, mixed-mode office rooms are the most common mode. The occupants in AC rooms occasionally opened windows at the same time as using the AC. In the naturally ventilated office buildings, fans were window are often used simultaneously.

- The occupants' thermal feelings affected the window opening behaviour and the use of the fans. In summer, when the temperature rose to a certain value, the temperature fluctuations cannot affect the window behaviour, but influenced the use of the fan. Indoor relative humidity and architectural design parameters had correlations with adaptive behaviour.

The limitations of this study are unavoidable. The basis of this summer research of four mixed-mode office case study can only represent part of the targeted building type. More accurate results require longer survey times and a larger range of research subjects. In addition, accurate everyday monitoring of occupation and absence in the investigated rooms during the observation period is necessary for future research. Therefore, when it is subtracted from its context, the data collected and the results analysis in this research may have been over-simplified in some way.

## Acknowledgement

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## References

- Baker N, Standeven M., (1997). *A behaviour approach to thermal comfort assessment*. *International Journal of Solar Energy*, 19(1), pp.21-35.
- Haldi F, Robinson D, (2009). *Interactions with window opening by office occupants*. *Building and Environment*, pp.2378-95.
- Herkel S, Knapp U., (2008). *Towards a model of user behaviour regarding the manual control of windows in office buildings*. *Building and Environment*, 43, pp. 588-600.
- Hong T, Lin H.W., (2013). *Occupant Behaviour: Impact on energy use of private offices*. Berkeley, CA: Lawrence Berkeley National Laboratory.
- IBM SPSS, (2017). <https://www.ibm.com/uk-en/marketplace/spss-statistics>
- Parys W, Saelens D., (2011). *Coupling of dynamic building simulation with stochastic modelling of occupant behaviour in offices - a review-based integrated methodology*. *Journal of Building Performance Simulation*, pp. 1-20.
- Simona D, Hong T., (2014). *A data-mining approach to discover patterns of window opening and closing behavior in offices*. *Building and Environment*, 82, pp. 726-739.
- U.S Department of Energy, (2011). *2011 Table of contents*. Retrieved March 31, 2014. Building Energy Data Book. <http://buildingsdatabook.doe.gov>

- Valentina F, Rune V.A., (2012). *Occupants' window opening behaviour: A literature review of factors influencing occupant behaviour and models*. Building and Environment, 58, pp.188-198.
- Yun F, Steemers K., (2002). *Time-dependent occupant behaviour models of window control in summer*. Building and Environment, 43, pp. 1471-82.

# The Impact of Natural Ventilation on Indoor Thermal Comfort in Office Buildings in the Mediterranean Climate

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**Abstract:** The aim of this paper is to quantitatively investigate the impact of natural ventilation on indoor thermal comfort in office buildings, in southern Europe. For this purpose, a field research study was conducted in a typical open-plan office layout of a typical medium-weight construction, in the urban centre of Nicosia, Cyprus, during the hot, summer season. The analysis is achieved through the interpretation of the in situ measurements of air and globe temperature and air velocity in the indoor and outdoor environments. Initially, the effectiveness of various ventilation strategies, i.e., daytime, night-time as well as full-day (24-hour) ventilation, was assessed. The analysis of the results shows that night ventilation is the most effective strategy for passive cooling during the hot summer period, compared to the other two ventilation strategies. Furthermore, in the case of night ventilation, an in-depth investigation was conducted, using different window opening patterns, i.e. single-sided and cross-ventilation. The results indicate that the night-time cross-ventilation strategy takes full advantage of the relatively low outdoor air temperatures during the night hours. The specific strategy reduces peak indoor air temperatures during the following day and thus drastically improves indoor thermal conditions during the operating hours of the office buildings. In terms of thermal performance analysis, Cooling Degree-Hours (CDH) was used as a quantitative indicator of the thermal performance efficiency of each ventilation strategy and window opening pattern. The research findings are presented in a comparative manner and evaluated in a quantitative way, offering valuable information to the relevant field. Moreover, they confirm the positive contribution of natural ventilation to passive cooling in typical open-plan office layouts, in the hot and dry climatic conditions of the Mediterranean basin as well as in other areas, where similar climatic conditions can be found.

**Keywords:** natural ventilation, passive cooling, thermal comfort, cooling degree-hours, hot and dry climate

## Introduction

On a global scale, the largest use of energy in office buildings is connected with providing satisfying thermal comfort to the occupants. Particularly, in warm climates the energy consumption is mostly associated with cooling while in cold climates it is associated with heating. Air-conditioning units, as a means of thermal cooling, is becoming more and more popular in the developed countries. However, the use of air-conditioners causes several problems. One of them is the serious increase of peak electricity loads, which lead to the building of additional plants by utilities in order to satisfy seasonal demand. These plants operate for a short period of time increasing the average cost of electricity. Another problem refers to the emissions of refrigerant gases used in air-conditioning installations that significantly affect ozone depletion and global warming. Moreover, air conditioning is associated with indoor air contamination with organic dust that may lead to microbial growth, mould and fungal growth (Santamouris, 2006).

In order to avoid the cost –financial and environmental– of air conditioning, bioclimatic architecture can extend the thermal comfort zone by integrating passive cooling strategies in the design of office buildings. The efficiency of the different passive cooling strategies depends on the climatic conditions of the region where the building is located

(Givoni, 1991). In warm arid climates, passive cooling strategies such as proper shading, evaporative cooling, natural ventilation and high thermal mass are proposed by several studies (Philokyprou et al, 2017). According to a number of studies, natural ventilation constitutes one of the most important cooling strategies in warm climates (Siew et al, 2011; Michael et al, 2014). Natural ventilation may be used either directly for cooling purposes when the outdoor environmental conditions are within comfort limits, i.e. daytime ventilation or indirectly, in order to improve indoor thermal conditions during the following day, i.e. night ventilation (Santamouris, 2006). In some cases hybrid ventilation systems can achieve better indoor thermal conditions and energy conservation (Taheri et al, 2016; Yao et al, 2009).

According to Givoni (1998), different natural ventilation strategies should be applied in different climatic conditions. More specifically, daytime ventilation is most appropriate when the maximum air temperature of the external environment varies between 28 and 32°C and the indoor wind speed varies from 1.5 to 2m/s. At the same time, the diurnal fluctuation should be less than 10°C. In contrast, night ventilation is preferable in regions where nocturnal outdoor air temperature is around 20°C and the diurnal temperature fluctuation is more than 10°C. A number of studies were performed in this specific research field indicating that night ventilation is a more efficient strategy, compared to full-day and daytime ventilation in warm climates (Jamaludin et al, 2014; Kubota et al, 2015; Santamouris et al, 2010). Field studies in vernacular dwellings of Cyprus have also shown that night ventilation is the most appropriate natural ventilation strategy for warm arid climates (Michael et al, 2017).

A series of field studies indicated that thermal mass, window size and shadings can significantly affect the efficiency of night ventilation strategy. A simulation study to evaluate the effects of thermal mass, window size and night ventilation during summer period was carried out by Amos-Abanye et al (2013) in the warm humid climate of Ghana. The study showed that the increase of thermal mass, in combination with night ventilation, results in lower peak temperatures during the next day, while the increase of window-to-floor ratio reduces the cooling efficiency of the system. Another relevant field study by Le Roche and Milne (2004) presented the significant effect of thermal mass and window size to the efficiency of a cooling system that uses night ventilation strategy.

The present research aims to quantitatively investigate the impact of natural ventilation on indoor thermal comfort in office buildings in southern Europe by conducting field measurements during the cooling period, i.e. summer period, in an office building in Nicosia, Cyprus. In this framework, different ventilation strategies and different window opening patterns are examined. The research findings are presented in a comparative manner and evaluated in a quantitative way, offering valuable information to the relevant field. Moreover, they confirm the positive contribution of natural ventilation on passive cooling in typical open-plan office layouts in the hot and dry climatic conditions of the Mediterranean basin as well as in other areas, where similar climatic conditions can be found.

## **Research methodology**

### ***Description of case study area and climatic conditions***

For the needs of the present research, a typical open-plan office layout of a typical medium-weight construction, located in the urban centre of Nicosia, Cyprus, was chosen for an in-depth investigation. The island has Mediterranean climate characterized by hot-dry summers and cold-wet winters. Nicosia is located at latitude 35°10' N and longitude 33°21' E

and belongs to the lowland region of the island, i.e. climatic zone 2. According to the meteorological data of the period of 1991 to 2005 (Department of Meteorology, Cyprus), mean temperatures during the hottest months, i.e. July and August, reach 29.7°C while mean maximum temperatures during the same period reach 37.2°C. Mean temperatures during the coldest months, i.e. January and February, reach 10.6°C with mean minimum temperature 5.2°C. Diurnal temperature fluctuations reach 16°C during summer months and range from 8 to 10°C during winter months. The annual mean precipitation is 342.2mm.

According to Milne-Givoni (1979), the appropriate passive design strategies during the cooling period in Cyprus, i.e. from June to September, are ventilation, night ventilation and evaporative cooling. Daytime ventilation should be carefully applied only when the exterior temperature is lower compared to the interior temperature. Moreover, the combination of natural ventilation with thermal mass is considered beneficial.

### **Description of case study building**

The field measurements were conducted in a five-storey building located in the urban centre of Nicosia, in an area where a continuous building system is applied. Most of the buildings in the area have two or three floors, while the area under investigation is located at the fourth floor of the building, allowing the unobstructed entrance of the wind within the indoor space of the floor. The floor under study is characterized by an open-plan layout as shown in Figure 1. The thickness of the external wall of the building envelope is approximately of 0.35m, consisting of a reinforced concrete load bearing structure and hollow ceramic brick walls, plastered by cement-based mortar rendering. The upper concrete slab is covered by suspended ceiling tiles made of mineral wool tiles, while the lower concrete slab is covered by a fixed carpet. The openings are filled metal frame with single glazed. The window openings reach up to the ceiling height, i.e. 2.60m, with a window-to-floor percentage of 23%. More specifically, there are four glazed windows at the north side of the layout, i.e. A-D, two glazed doors at the east, i.e. E-F, two glazed windows at the west, i.e. H-I, and a metal door at the south side of the plan, i.e. G.

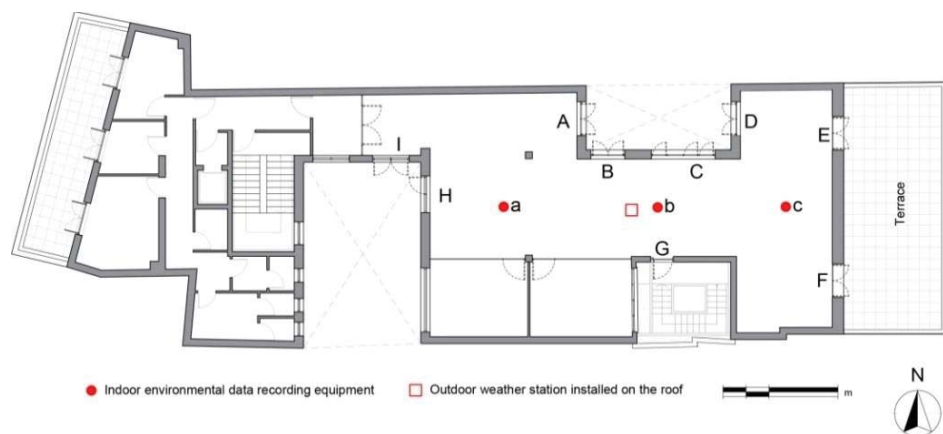


Figure 1. Plan layout where the openings A to I and the locations of the installed recording equipment for indoor and outdoor environmental conditions are indicated.

### **Field study methodology**

For the investigation of the impact of natural ventilation on indoor thermal comfort in office buildings, a field study was carried out during the hot summer period, specifically from 31<sup>st</sup> July to 29<sup>th</sup> August 2017. During this period, the area was not used by occupants and no activity took place. This eliminated the internal thermal load from human occupancy;



however, it serves the needs of the study for comparative assessment of the impact of natural ventilation under different conditions. The recordings of indoor environmental parameters were made at ten-minute intervals, using appropriate recording equipment. More specifically, for the indoor temperature measurements two LSI-Lastem Heat Shield base modules (ELR610M) were used. The equipment has a data logging interval of 10s, environmental limits from -20 to 60°C and includes natural wet bulb, dry bulb and globe thermometers with an accuracy of  $\pm 0.3^{\circ}\text{C}$ ,  $\pm 0.4^{\circ}\text{C}$  and  $\pm 0.3^{\circ}\text{C}$  respectively. At the same time, for the air velocity measurements, a Hot wire LSI Anemometer ESV125, with measurements range from 0.01m/s to 20m/s and an accuracy of 0.01m/s was used. The equipment was placed in selected locations, as shown in Figure 1. The temperature sensors were placed at a height of 1.3m and the wind sensor at a height of 1.45m above floor level, which was approximately the mean height of the window openings, i.e., A-D and H-I. At the same time, an outdoor weather station was installed at the roof of the building at the height of 20m above the street level, i.e. approximately 10m above the average height of buildings in the surrounding environment. More specifically, a Vantage Pro 2 Plus weather station, with measurement range from -40 to 60°C, a data logging interval of 10-12s, and an accuracy of  $\pm 0.3^{\circ}\text{C}$  were used for outdoor air temperature and air velocity with measurements range from 1m/s to 809m/s.

In this context, different ventilation strategies were examined, i.e. daytime ventilation, full-day (24-hour) ventilation and night ventilation. In this study, daytime refers to the time of the day between 07:00h and 21:00h; night-time refers to the time of the day between 21:00h and 07:00h. Thus, during daytime ventilation the windows remain open from 07:00h to 21:00h. During full-day ventilation the windows remain open for 24 hours, i.e. from 07:00h to 07:00h. Similarly, during night time ventilation the windows remain open from 21:00h to 07:00h. The openings of the floor under study remained either open or closed, depending on the strategy applied. The recordings of the indoor and outdoor environmental conditions during each ventilation strategy lasted two consecutive days. Before that, a two days period with no ventilation was recorded to be used as a reference scenario. The ventilation strategies investigated during the field study, are summarized in Table 1.

Table 1. Ventilation strategies and opening patterns investigated during the field study period

	Windows and doors remained open									Open windows	
	A	B	C	D	E	F	G	H	I	7h – 21h	21h – 7h
<b>Ventilation Strategies under study</b>											
1 No Ventilation	-	-	-	-	-	-	-	-	-	-	-
2 Daytime Ventilation	•	•	•	•	•	•	•	•	•	•	-
3 Full-day Ventilation	•	•	•	•	•	•	•	•	•	•	•
4 Night Ventilation	•	•	•	•	•	•	•	•	•	-	•

Emphasis was put on the night ventilation strategy, by investigating different opening patterns during night ventilation, i.e. two different types of single sided ventilation and two types of cross ventilation. For single sided ventilation I (Case I), openings B and C remained open, while for single sided ventilation II (Case II), all the windows on the northern side of the plan layout remained open (A, B, C and D). For the case of cross ventilation I (Case III) the openings B, D, F and H remained open, while in the case of cross ventilation II (Case IV) all the openings of the floor remained open (A, B, C, D, E, F, G and I). In all Cases, the openings remained open during night-time, i.e. from 21:00h to 07:00h, and closed during daytime, i.e. from 07:00h to 21:00h. For each case study, the recording period was two consecutive days. The opening pattern cases under study are summarized in Table 2.

Table 2. Opening patterns investigated during the field study period

	Windows and doors remained open									Open windows	
	A	B	C	D	E	F	G	H	I	7h – 21h	21h – 7h
<b>Window opening patterns under study during night ventilation</b>											
5 Single Sided I – Case I	-	●	●	-	-	-	-	-	-	-	●
6 Single Sided II – Case II	●	●	●	●	-	-	-	-	-	-	●
7 Cross Ventilation I – Case III	-	●	-	●	-	●	-	●	-	-	●
8 Cross Ventilation II – Case IV	●	●	●	●	●	●	●	●	●	-	●

### Data analysis methodology

The recorded data in regard to the indoor and outdoor environment collected during each ventilation strategy as well as each night ventilation Case were evaluated by comparing the indoor and outdoor air temperatures. In addition, the Temperature Difference Ratio (*TDR*), which was proposed by La Roche and Givoni (La Roche and Givoni, 2002) was calculated. *TDR* was successfully used in studies (La Roche and Milne, 2004) for the comparison of passive cooling systems with different configurations. It can be calculated using the following equation:

$$TDR = \frac{T_{\max\_out} - T_{\max\_in}}{T_{fluctuation\_out}} \quad (\text{Equation 1})$$

where  $T_{\max\_out}$  is the maximum outdoor air temperature,  $T_{\max\_in}$  the maximum indoor air temperature and  $T_{fluctuation\_out}$  is the difference between the maximum outdoor temperature ( $T_{\max\_out}$ ) and the minimum outdoor temperature ( $T_{\min\_out}$ ). Equation 1 is valid only when there is a correlation between the outdoor fluctuation and the difference between the indoor and outdoor maximum temperatures. In a naturally ventilated building the *TDR* value cannot be higher than 1 and it can be presented as a percentage. A higher value of *TDR* indicates a larger peak temperature difference between indoors and outdoors and thus a more efficient cooling strategy. This indicator reduces the effect of outdoor air temperatures which vary from day to day, thus it is selected as an appropriate comparative method of assessment for the evaluation of the cooling performance of the different ventilation strategies and night ventilation case scenarios.

The Adaptive Comfort Standard (ACS) which is incorporated in ASHRAE Standard 55 (ASHRAE, 2013) was used for the assessment of thermal comfort. The ACS can be used for occupant-controlled naturally conditioned spaces, since its calculation is based on the fact that the occupants of naturally ventilated spaces have different expectations of thermal comfort than those of technically supported indoor spaces, due to their adaptation to outdoor conditions. The occupants of the space are considered to engage in near sedentary activities with metabolic rates ranging from 1.0 to 1.3 met while expected to use typical clothing insulation for hot summer period of about 0.5 clo.

For the purpose of this study, the calculation of the operative temperature ( $t_o$ ) is based on an average air temperature ( $t_a$ ) and mean-radiant temperature ( $t_r$ ), as shown in Equation 2. Value *A* is a function of the relative air speed ( $V_r$ ) as shown in Table 3. Air velocity measurements for the internal environment ranged from 0.0m/s to 0.8m/s for the ventilation strategies and from 0.0m/s to 0.3m/s for the window opening patterns case scenarios during night ventilation.

$$t_o = At_a + (1 - A)t_r \quad (\text{Equation 2})$$

Table 3: Value *A* as a function of the relative air speed

$V_r$	< 0.2 m/s	0.2 to 0.6 m/s	0.6 to 1.0 m/s
<i>A</i>	0.5	0.6	0.7

Moreover, air temperature ( $t_a$ ) is recorded directly, while mean radiant temperature ( $t_r$ ) is calculated using the Equation 3. The parameters included in Equation 3 are the globe temperature ( $t_g$ ), air velocity ( $V_a$ ), air temperature ( $t_a$ ), globe diameter ( $D$ ) and emissivity ( $\varepsilon$ ).

$$t_r = \left[ (t_g + 273)^4 + \frac{1.10 \times 10^8 V_a^{0.6}}{\varepsilon D^{0.4}} (t_g - t_a) \right]^{1/4} - 273 \quad (\text{Equation 3})$$

Furthermore, the acceptability indoor operative temperatures were determined using the 80% and 90% acceptability limits. The 80% acceptability limits were calculated as indicated in Equations 4 and 5, while the corresponding 90% acceptability limits resulted after subtracting 1°C and adding 1°C to the upper and lower 80% acceptability limit respectively. The prevailing mean outdoor air temperature ( $\overline{t_{pma(out)}}$ ) is the arithmetic average of the mean daily outdoor temperatures over a period of seven sequential days prior to the day in question.

$$\text{Upper 80\% acceptability limit (}^\circ\text{C)}: 0.31\overline{t_{pma(out)}} + 21.3 \quad (\text{Equation 4})$$

$$\text{Lower 80\% acceptability limit (}^\circ\text{C)}: 0.31\overline{t_{pma(out)}} + 14.3 \quad (\text{Equation 5})$$

Finally, the Cooling Degree-Hour value (CDH) was used as a quantitative indicator for the evaluation of the cooling performance efficiency of each ventilation strategy. The Cooling Degree-Hour value equals to the sum of the differences between hourly average operative temperatures and the upper acceptability limit of indoor operative temperature during occupied hours. For the purpose of this study, the occupied hours are considered to be from 7:00h to 21:00h. The value of the CDH in a given day is calculated using the Equation 6, where  $N$  is the number of occupied hours in a day with average hourly operative temperature higher than the upper acceptability limit level,  $T_{(o\_average)}$  the average hourly operative temperature and  $T_{(upper\_limit)}$  is the upper acceptability limit to which the degree-hours are calculated.

$$CDH = \sum_{i=1}^N (T_{o\_average} - T_{upper\_limit})^+ \quad (\text{Equation 6})$$

## Field study results

The recorded field data referring to the outdoor wind environment are presented in wind rose diagrams (Figure 2). Specifically, the prevailing daytime wind flow is west and north-northeast with an average wind speed of 2m/s, while the prevailing night-time wind flow is west and south with an average wind speed of 1.3m/s.

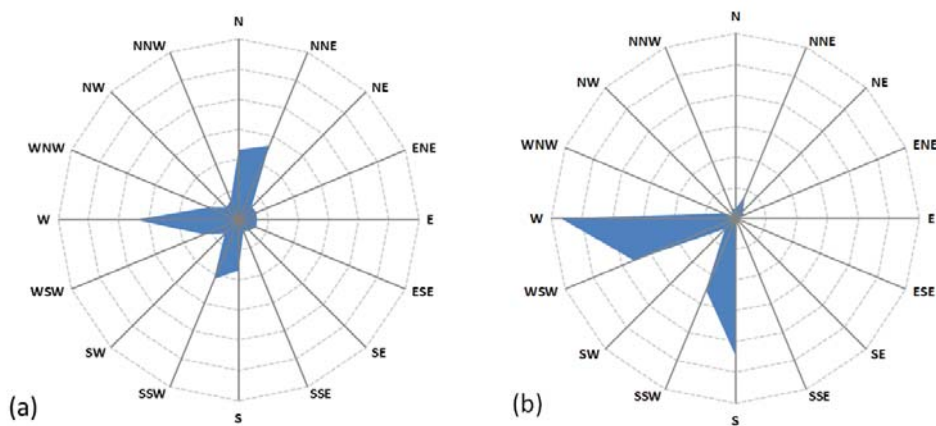


Figure 2. Analysis of the outdoor wind environment during (a) daytime and (b) night-time.

### ***Natural ventilation strategies***

As shown in Figure 1, indoor environmental data recorders were placed on selected positions of the floor layout. The data collected were evaluated on a comparative basis, indicating only slight differences, which can be attributed to the different proximities of the recording devices from the external walls and openings of the building. For the needs of the present paper, the data used were the ones recorded by device (a). The recorded indoor and outdoor temperatures from 3<sup>rd</sup> July to the 8<sup>th</sup> August 2017 are presented in Figure 3, whereas, the assessment of thermal comfort is demonstrated in Figure 4. A period without any ventilation, i.e. from 31<sup>st</sup> July to 1<sup>st</sup> August 2017, was used as a reference scenario, while natural ventilation strategies, i.e. daytime, full-day and night ventilation, were investigated during the period between 2<sup>nd</sup> and 8<sup>th</sup> August 2017.

More specifically, during the period without any ventilation the indoor temperatures were fairly stable, with a mean diurnal fluctuation of 2.6°C, while the temperature fluctuation recorded in the external environment during the same period was 12.7°C. The stability of indoor air temperatures is associated with the positive contribution of building's high thermal mass. The daytime ventilation strategy was applied from 2<sup>nd</sup> to 3<sup>rd</sup> July. During this period, the daily indoor air temperatures followed the pattern of the external air temperatures, with the mean indoor air temperature being only 0.3°C lower than the outdoor environment. At the same time nocturnal indoor air temperatures were kept at significantly higher levels compared to the external ones. More specifically, the mean nocturnal indoor air temperature was 6.5°C above the respective temperature of the external environment. As shown in Figure 3, this value was similar to the respective nocturnal temperature difference, recorded during the period without any ventilation. The recorded data for the full-day ventilation strategy shows that the indoor air temperature followed the air temperature pattern of the outdoor environment throughout the day and night. Specifically, the mean daily indoor air temperature was only 0.3°C lower than the outdoor air temperature, similar to the recorded daily data during daytime ventilation strategy, while the mean nocturnal indoor air temperature was 2.1°C above the outdoor air temperature.

Finally, during the application of the night ventilation strategy, nocturnal indoor air temperatures followed the respective outdoor temperatures, with the mean indoor air temperature during night-time being 2.3°C higher than the respective one of the outdoor environment. This is very similar to the nocturnal temperatures recorded during the application of full-day ventilation. However, the indoor air temperatures recorded during the following day, remained at significantly lower levels compared to the temperatures recorded during the application of the other two strategies. More specifically, the mean indoor air temperature was 0.2°C lower than the respective outdoor temperature, while the peak indoor air temperature was significantly reduced by 4.0°C compared to the outdoor peak temperature. The above findings indicate that during night ventilation, heat energy is removed from the thermal mass of the building envelope, ensuring thus better thermal conditions during the following day.

In terms of thermal comfort assessment, the comfort zone during the period under investigation ranges from 23.6–23.8°C to 30.6–30.8°C for 80% acceptability and from 24.6–24.8°C to 29.6–29.8°C for 90% acceptability. The graph shows that operative temperatures during the period without any ventilation exceed the upper acceptability limits for all the hours of the day and night. The operative temperatures recorded during daytime ventilation

strategy, exceed the upper acceptability limit of 80% for 98.3% of the time and the upper 90% acceptability limit for 100% of the time. As shown in Figures 3 and 4, during the application of specific strategy, a rapid increase of air and operative temperature is observed during the night hours when the windows are closed. This is related to the heat energy absorbed by the thermal mass of the building envelope during daytime and the heat retained in the indoor space during night-time when the external temperatures are lower.

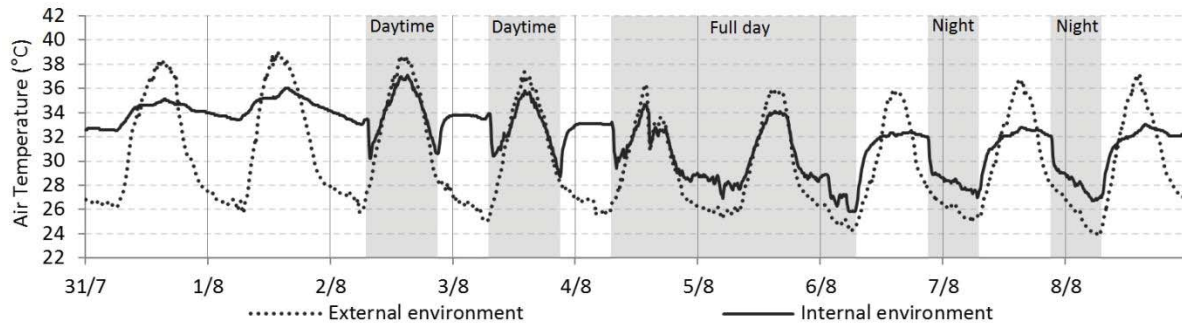


Figure 3. Indoor and outdoor air temperatures recorded during the ventilation strategies under study.

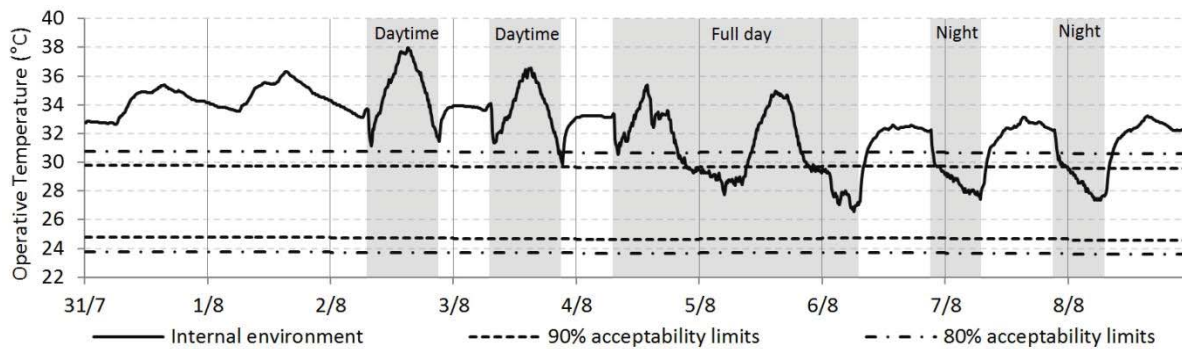


Figure 4. Operative temperatures for thermal comfort assessment of natural ventilation strategies under study

During the application of full-day ventilation strategy, the daily operative temperatures exceed the upper acceptability limits, whereas, the nocturnal operative temperatures remain within the upper acceptability limit. More specifically, the indoor operative temperatures remain within the upper 80% acceptability limit for 53% of the time and within the upper 90% acceptability limit for 43% of the time. The recorded data demonstrate improved nocturnal indoor temperatures during full-day ventilation compared to the daytime ventilation strategy. During the night ventilation strategy, the recorded indoor operative temperatures remain within the upper 80% acceptability limit for 46% of the time and 38% of the time within the upper 90% acceptability limit. Even though the percentage of the hours that exceed the upper acceptability limits recorded during the night ventilation strategy is lower than the one recorded during the full-day ventilation strategy, the lower peak operative temperature during the application of night ventilation, i.e. 2.1°C lower than the respective one during the full-day ventilation, indicates improved thermal behaviour during the application of night ventilation strategy. The thermal comfort assessment indicates that night ventilation strategy is the most efficient cooling strategy compared to the daytime and full-day ventilation strategies.

#### *Cooling degree-hours (CDH) for different ventilation strategies under study*

CDH are fairly high for all cooling strategies under study. This is due to the uninsulated building envelope, as well as, due to the high percentage of window-to-floor area that increases the solar heat gains entering the building. During the period without any



ventilation, the cooling degree-hour values for the two days under investigation are 55.5 and 65.0 for 80% acceptability and 69.5 and 79.0 for 90% acceptability, while during the period of daytime ventilation strategy, the CDH values are 60.8 and 44.3 for 80% acceptability limit and 74.8 and 58.3 for 90% acceptability limit. The CDH values calculated during daytime ventilation are slightly lower to the ones calculated during the period without any ventilation. During full-day ventilation strategy the CDH values are 27.8 and 26.1 for 80% acceptability limit and 41.3 and 37.0 for 90% acceptability limit indicating lower CDH values compared to the values calculated during daytime ventilation. Finally, during the night ventilation strategy the CDH values are lower compared to all other strategies under study, i.e. 21.1 and 22.7 for 80% acceptability and 34.1 and 35.7 for 90% acceptability, indicating higher cooling performance efficiency.

#### *Temperature Difference Ratio (TDR) for different ventilation strategies under study*

The TDR for the case without any ventilation has an average value of 24.8%, as the peak indoor air temperatures are averagely 3.1°C lower than the peak outdoor air temperatures. The average TDR value for the daytime ventilation strategy is 12.7% while the average TDR value for the full-day ventilation strategy is 15.6%. Night ventilation strategy has the highest TDR value, i.e. averagely 32.2%, indicating the highest cooling performance efficiency compared to the other ventilation strategies under study (Table 4).

Table 4: Temperature Difference Ratio of the ventilation strategies under study.

Ventilation Strategy	$T_{\max\_out}$	$T_{\max\_in}$	$T_{\min\_out}$	$T_{fluctuation\_out}$	Date of investigation	Temperature Difference Ratio (%)		
No Ventilation (reference)	38.4	35.1	26.2	12.2	31-07-17	27.0	average	24.8
	39.0	36.0	25.7	13.3	01-08-17	22.6		
Daytime Ventilation (all openings open)	38.7	37.1	25.8	12.9	02-08-17	12.4	average	12.7
	37.4	35.8	25.1	12.3	03-08-17	13.0		
Full-day Ventilation (all openings open)	36.3	34.7	25.6	10.7	04-08-17	15.0	average	15.6
	35.8	34.1	25.3	10.5	05-08-17	16.2		
Night Ventilation (all openings open)	36.7	32.8	24.9	11.8	07-08-17	33.1	average	32.2
	37.2	33.0	23.8	13.4	08-08-17	31.3		

#### **Window opening patterns applied during Night Ventilation**

The research results of the previews section indicated night ventilation as the most effective strategy for the cooling of typical office buildings in Cyprus and in other areas with similar climatic conditions and building typologies. A further in-depth investigation of the effectiveness of various window opening patterns during night ventilation strategy is presented in the current section. The indoor and outdoor air temperatures recorded during the application of different window opening pattern cases, for the period from the 10<sup>th</sup> to the 20<sup>th</sup> of August 2017, are presented in Figure 5, whereas the assessment of thermal comfort is presented in Figure 6.

With regard to the assessment of the different window opening patterns during night ventilation, important findings are recorded in relation to the nocturnal indoor temperatures for each pattern applied. Specifically, during the period without any ventilation the mean nocturnal indoor air temperature is 6.5°C above the respective mean nocturnal temperature of the external environment. During the single sided I pattern scenario (Case I), i.e. openings B and C remained open, the mean nocturnal indoor air temperature is 4.5°C above the respective temperature of the outdoor environment while during single sided II pattern scenario (Case II), i.e. the openings A, B, C and D remained open, the difference between the indoor and outdoor mean nocturnal temperature



decreased into 2.8°C, indicating the higher impact of Case II compared to Case I. The lower temperature discrepancy between indoor and outdoor air temperature of Cases I and II indicates Case II as a more effective ventilation strategy. During cross ventilation I (Case III), i.e. openings B, D, F and H remained open, the mean nocturnal indoor temperature is 4.0°C higher than the respective outdoor temperature while in the case of cross ventilation II (Case IV), i.e. all the openings remained open, the respective difference is 2.7°C. It should also be noted that the mean nocturnal outdoor temperature recorded during the Case III is fairly lower than the respective temperatures recorded during the period under study, i.e. 10<sup>th</sup> to the 20<sup>th</sup> of August 2017, however the minimum temperature recorded during the Case IV is 0.3°C lower than the respective temperature recorded during Case III.

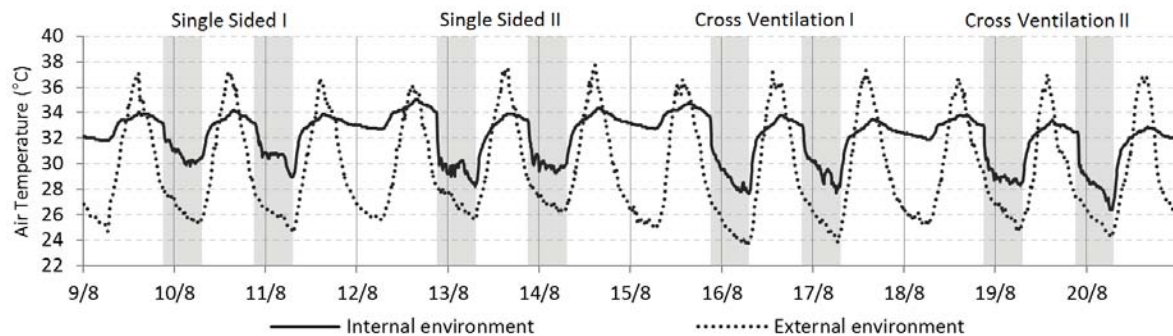


Figure 5. Indoor and outdoor air temperatures recorded during the opening patterns under study.

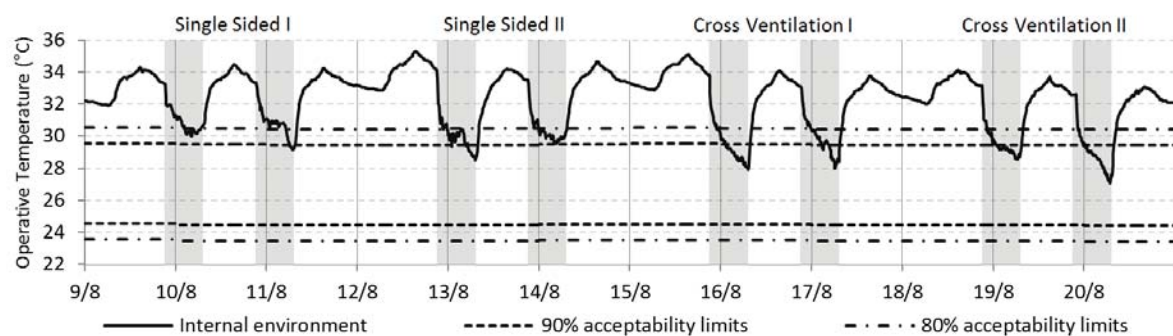


Figure 6. Operative temperatures for thermal comfort assessment of the opening patterns under study.

In terms of thermal comfort assessment, during the application of Case I the operative temperatures remain within the upper 80% acceptability limit for 15.6% of the time and only for 3.8% of the time within the upper 90% acceptability limit. During the the application of Case II the operative temperatures remain within the comfort limits for 34.0% of the time for 80% acceptability limit and for 7.6% of the time within the 90% acceptability limit. The operative temperatures recorded during Case III remain within the comfort limits for 36.5% of the time for 80% acceptability and for 21.5% of the time within the 90% acceptability limit. Finally the respective temperatures for Case IV remain for 40.6% of the time within the 80% acceptability limits and for 30.6% of the time within the 90% acceptability limit. The recorded data indicated that the more window openings remained open the more percentage of the time the operative temperatures remained within the comfort acceptability limits. Moreover, these findings indicated that the cross ventilation is more efficient cooling strategy compare to single sided ventilation.

#### *Cooling degree-hours (CDH) for different opening patterns under study*

The CDH values calculated during the application of Case I are 42.2 and 38.8 for 80% acceptability limit and 56.2 and 52 for 90% acceptability limit. During the application of Case

II, CDH values are slightly lower to the ones calculated during the application of Case I. More specifically, CDH value calculated during Case II are 37.5 and 41.9 for 80% acceptability and 50.5 and 55.9 for 90% acceptability. During Case III the calculated CHD values are 34.8 and 32.2 for 80% acceptability limits and 47.8 and 45.4 for 90% acceptability limits. Finally, during Case IV application the CDH values are 31.2 and 24 for 80% acceptability limits and 44.6 and 38 for 90% acceptability limits. The above research findings, confirm the positive contribution of the extensive ventilation during the night-time, as well as the higher impact of cross ventilation compare to single sided ventilation in the indoor thermal comfort during the cooling period.

#### *Temperature Difference Ratio (TDR) for different opening patterns under study*

The average TDR value during the application of the Case I is 24.5%, while the average peak indoor air temperatures is 3.0°C lower than the average peak outdoor air temperature. The average TDR value for the Case II is 29.2%, while the difference between indoor and outdoor peak air temperatures is averagely 3.4°C. The average TDR value for the Case III is 26.5%, while the peak indoor air temperatures are averagely 3.6°C lower than the peak outdoor air temperatures. The difference in indoor and outdoor peak air temperatures for Case III indicates higher cooling performance efficiency compared to Case II. On the contrary to the above, the TDR value for Case III is lower than the one calculated for the Case II. This is due to the decrease outdoor temperatures recorded during the application of Case III and thus the increase of the outdoor temperature fluctuation of about 2.0°C. Finally, the Case IV demonstrated the highest TDR value, i.e. averagely 30.2%, while the average peak air temperature between indoor and outdoor is 3.8°C. The above indicating the highest cooling efficiency of Case IV compared to the other opening patterns under study (Table 5).

Table 5: Temperature Difference Ratio of the window opening patterns under study.

Ventilation Strategy	$T_{\max\_out}$	$T_{\max\_in}$	$T_{\min\_out}$	$T_{fluctuation\_out}$	Date of investigation	Temperature Difference Ratio (%)		
Single Sided I (B & C open)	37.3 36.7	34.2 33.9	25.3 24.6	12.0 12.1	10-08-17 11-08-17	25.8 23.1	average	24.5
Single Sided II (A, B, C & D open)	37.4 37.7	33.9 34.4	25.6 26.2	11.8 11.5	13-08-17 14-08-17	29.7 28.7	average	29.2
Cross Ventilation I (B, D ,F & H open)	37.2 37.3	33.8 33.5	23.5 23.8	13.7 13.5	16-08-17 17-08-17	24.8 28.1	average	26.5
Cross Ventilation II (all openings open)	37.0 36.8	33.4 32.9	24.7 24.3	12.3 12.5	19-08-17 20-08-17	29.3 31.2	average	30.2

## **Conclusions**

The research analysis was achieved through the interpretation of the in situ measurements of indoor and outdoor environmental parameters conducted in a typical open-plan office layout of a typical medium-weight construction, during a period that the area was not used by the occupants. The results analysis shows that night ventilation is the most effective strategy for passive cooling during the hot summer period, compared to the daytime and full-day ventilation strategies. Furthermore, in the case of night ventilation, an in-depth investigation using different window opening patterns, indicating that the night-time cross-ventilation strategy takes full advantage of the relatively low outdoor air temperatures during the night hours. The specific strategy reduces peak indoor air temperatures during the following day and thus drastically improves indoor thermal conditions during the operating hours of the office buildings.

The findings of the current research were analysed in a comparative manner and evaluated in a scientific quantitative way, offering valuable knowledge in the field of passive cooling ventilation. The research study gives evidence to and quantifies the effectiveness of cooling ventilation strategies, while at the same time it establishes that the night ventilation strategy has higher impact on the cooling effect of the indoor spaces, compared to daytime and full-day ventilation. Furthermore, the investigation of different window opening pattern cases during the application of night ventilation reveals the effectiveness of the cross-ventilation compared to the single-sided ventilation. The current research study confirms the positive contribution of natural ventilation for passive cooling in typical open-plan office layouts in the hot and dry climatic conditions of the Mediterranean basin, as well as in other areas where similar climatic conditions can be found. Moreover, the study introduces a multi-criteria evaluation methodology for the assessment of natural ventilation as a cooling strategy offering thus valuable information in the relevant field.

## References

- Amos-Abanye, S., Akuffo, F.O. and Kutin-Sanwu, V. (2013), Effect of Thermal Mass, Window Size and Night-Time Ventilation on Peak Indoor Air Temperature in the Warm-Humid Climate of Ghana, *The Scientific World Journal*, [online] Volume 2013, p. 9
- de Dear, R. and Brager, G.S. (2002), Thermal comfort in naturally ventilated buildings: revisions to ASHRAE Standard 55, *Energy and Buildings*, 34, pp.549-561
- Givoni B., (1991), Comfort, climate analysis and building design guidelines, *Energy and Buildings*, 18, pp. 11-23
- Givoni, B. (1998), *Climate considerations in building and urban design*. New York: Van Nostrand Reinhold.
- Jamaludin, A.A., Hussein, H., Mohd Ariffin, A.R. and Keumala, N. (2014), A study on different natural ventilation approaches at a residential college building with the internal courtyard arrangement, *Energy and Buildings*, 72, pp.340-352
- Kubota, T. and Chyee Toe, D.H. (2015), Application of passive cooling techniques in vernacular houses to modern urban houses: A case study of Malaysia, *Procedia-Social and Behavioral Sciences*, 179, pp. 29-39
- Le Roche, P. and Givoni, B. (2002), The effect of heat gains on a radiant cooling system, PLEA2002
- Le Roche, P. and Milne, M. (2004), Effects of window size and thermal mass on building comfort using an intelligent ventilation controller, *Solar Energy*, 77, pp. 421-434
- Michael, A., Demosthenous, D. and Philokyprou, M. (2017), Natural ventilation for cooling in Mediterranean climate A case study in vernacular architecture of Cyprus, *Energy and Buildings*, 144, pp. 333-345
- Michael, A., Philokyprou, M. and Argyrou, C. (2014), Documentation and evaluation of the positive contribution of Natural Ventilation in the Rural Vernacular Architecture of Cyprus, *EuroMed 2014*, pp. 310-320
- Milne, M. and Givoni, B. (1979), Architectural Design Based on Climate, In: D. Watson, ed., *Energy Conservation through Building Design*, New York: McGraw-Hill, pp. 96-113
- Philokyprou, M., Michael, A., Malaktou, E. and Savvides, A. (2017), Environmentally responsive design in Eastern Mediterranean. The case of vernacular architecture in the coastal, lowland and mountainous regions of Cyprus, *Building and Environment*, 111, pp. 91-109
- Santamouris, M., (2006), Ventilation for Comfort and Cooling: The State of the Art. In: M. Santamouris and P. Wouters, ed., *Building ventilation: the state of the art*, 1st ed. London: Earthscan, pp. 217-245
- Santamouris, M., Sfakianaki, A. and Pavlou, K. (2010), On the efficiency of night ventilation techniques applied to residential buildings, *Energy and Buildings*, 42, pp.1309-1313
- Siew, C.C., Che-Ani, A.I., Tawil, N.M., Abdullah, N.A.G. and Mohd-Tahir, M. (2011), Classification of Natural Ventilation Strategies in Optimizing Energy Consumption in Malaysian Office Buildings, *Procedia Engineering*, 20, pp. 363-371
- Taheri, M., Schuss, M., Fail, A. and Mahdavi, A. (2016), A performance assessment of an office space with displacement, personal, and natural ventilation systems. *Building Simulation*, 9 (1), pp. 89-100
- Yao, R., Li, B., Steemers, K. and Short, A. (2009), Assessing the natural ventilation cooling potential of office buildings in different climate zones in China. *Renewable Energy*, 34, pp. 2697-2705

# Influence of the glazing system on visual comfort in the elementary school buildings: Case study of a building in Eskisehir-Turkey

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**Abstract:** Various investigations have confirmed that pupils and teachers' performance and health depend significantly on the quality and amount of the daylight and indoor conditions. On the other hand, visual and thermal performance plays a significant role in energy efficient building design. The primary aim of using natural light in schools is not only increasing students' performance through the quality of light but also reducing the artificial energy consumptions and costs. Furthermore, building envelope design could improve the energy performance of the building, which could apply to the new and existing building. An appropriate design of windows causes to improve visual comfort by reducing the glare and distributing illuminance, and the thermal comfort by controlling the solar heat gain.

The study focuses on the impact of different transparency ratios (WWR), window combinations and directions on the visual comfort in the classrooms. The case building is one of the typical elementary school projects planned to construct in Eskisehir. Two classes of the building are selected to study; one of them is directed to the East, and the other one is headed to the West. These two classrooms are simulated with the aid of the lighting simulation programs DIALux Evo 6.0, which is verified by the International Commission on Illumination (CIE) to evaluate the visual comfort. Results of simulations for visual comfort are evaluated for two days in two different hours. Based on the academic calendar, 20 of March and 21 of December are selected as critical days and 10:00 a.m. and 02:00 p.m. are defined as crucial hours.

**Keywords:** Glazing System, Transparency Ratio, Daylight, School, Illumination Level

## Introduction

The environment has an extraordinary influence on the occupants' satisfaction and performance. It is clear and perceptible in the educational building that the proper indoor environments give an impression of vitality, with attractive spaces and a general feeling of satisfaction (Korsavi et al. 2016). Undoubtedly, appropriate educational environments contribute health and wellbeing for instructors and students; lighting that is an essential element to conduct human activities plays a critical role (UK Department for Education and Employment, 1999).

Educational buildings are the foundation of every country while they consume a significant portion of the nation's non-industrial energy needs; they are responsible for 15% of the total energy consumption. According to statistics of the Ministry of National Education of Turkey, 99156 school buildings existed in 2015-2016 academic year. During this educational year, about 23 million students studied, and more than 1 million 290 thousands of teachers worked in schools. These statistics indicate that almost one-fourth of Turkey's population spends the majority of their time in schools. Consequently, school buildings have the great importance of having the proper quality of illuminance and being high-energy performance buildings. This aspect will be more critical when considering that Turkish population consists of mostly young people (Turkish Ministry of National Education, 2015). The appropriate lighting design for a school is necessary to provide a lit environment which enables students and staff to carry out their specific activities comfortably and adequately in attractive and stimulating surroundings (UK Department for Education and Employment, 1999).

Proper daylight design can increase the attendance and achievement rates, reduce fatigue factors (Edwards and Torcellini, 2002), improve student health, and enhance general development (Michael and Heracleous, 2017). Lighting solely can be responsible for 70% of electrical energy consumption in schools (Delvaeye et al., 2016). Natural light eliminates noise and flickering from electric light sources and provides the best quality of light available in schools' spaces. Other investigations have indicated that students in windowless classes are more hostile, hesitant, and maladjusted. Also, they tend to be less interested in their work and complain more (UKessay, 2015). However, the definition and quantification of visual comfort are less standardised than thermal comfort, since it depends on the available daylight, glazing and screens that filter it, and visual task (Sicurella et al., 2012).

Furthermore, achieving proper lighting levels and increasing use of natural daylight can improve student performance. Classes with the most daylighting had a 20 percent better learning rate in math, and a 26 percent improved degree in reading, compared to those with little or no daylighting. Improving daylighting does not have to include a renovation. It can consist of a simple moving of stacked apparatus away from windows or even cleaning glazings to allow the natural light to shine in (Falken, 2012).

The amount of light that enters and the distributes within the space are principally determined by general glazing design aspects, such as the numbers of windows, the size of glazed areas and their disposition, and shape. With more windows in a room, the daylight will be more uniformly distributed in the space compared to a place that has just one single window. A glazing ratio of 40% for the South, East and West façade and 55% for North façade is recommended (Penny, 2012).

Windows are essential as they provide a natural variation of light through the day and external visual interest. For the window area to be adequate for this purpose, it is recommended to allocate at least 20% transparency ratio for the exterior wall. Windows do not only provide a lighting source but also providing a view out; they need to be considered regarding other environmental factors, e.g., the thermal and acoustic performance together with the energy efficiency of the building (Department for Education and Skills, 2003). Windows also affect other environmental factors, mainly thermal comfort, fresh air supply, energy efficiency and noise intrusion. Consequently, it can be seen that windows are a complicated part of building design and need special considerations to maximise the benefit and pleasure together with minimising dissatisfaction (UK Department for Education and Employment, 1999).

Natural light should be the prime means of lighting during daylight hours. Space is likely to be considered well lit if there is an average daylight factor of 4-5%. To have an adequate daylight illuminance level, in regular teaching areas, it is necessary to achieve a level of not less than 300 lux (Meresi, 2016). Spaces dedicated to detailed work such as art and craft classrooms need a minimum level 500 lux (UK Department for Education and Employment, 1999 and Department for Education and Skills, 2003). Furthermore, a minimum of 2% daylight factor at any desk in the classroom is a rigorous requirement; (Lechner, 2012; Al-Khatatbeh, 2017) nevertheless, the use of artificial lighting will be the design solution to encounter this necessity that is implementing in most cases (Donnelley, 2007).

Furthermore, daylight requirements are for a 2% daylight factor at all desk locations, or, if this is not provided, the perpetual artificial supplementary lighting is required to provide reasonable levels of illumination. A minimum of 2% at any desk in the classroom is a rigorous requirement; nevertheless, the use of artificial lighting will be the design solution to encounter this necessity that is implementing in most cases (Donnelley, 2007).



The Daylight Factor within a space depends on some parameters including the size and position of the transparent components, the dimensions of the area, the reflectance of the interior surfaces and the degree of external obstruction. It is not usually necessary for spaces with an average daylight factor of 5% or more to use artificial light. A room with an average daylight factor of 2% or less will require the frequent use of artificial light while a place with the value between 2% and 5% will need artificial lighting linked to the automatic daylight control system from October to March. Building Bulletin 90 (BB90) also recommends daylight uniformity ratios of 0.3-0.4 for side-lit rooms and 0.7 for top-lit halls (UK Department for Education and Employment, 1999 and RR Donnelley, 2007).

The primary aim of this research is to define a proper classroom module for elementary schools of Turkey with a particular emphasis on visual comfort of students based on the standards and guidelines. In Turkey, primary schools are mostly built according to the typical projects that are implemented by the Ministry of Public Works and Settlement. The study purpose to evaluate and apply energy efficient design principles for a classroom (orientations and transparency ratios) module, which is taken from the typical project. Illuminance level and daylight factor are compared in two different hours and days of the year.

## **Methodology**

The method of this study is based on simulation and calculation of a virtual model. Two different classrooms located in the opposite façades, East, and West, of a primary school, is selected to study. These example classrooms are repeated on other floors. Hence, two of these classes are chosen for daylighting evaluation.

The reference classrooms' models were created in DIALux Evo 6.0 daylighting software, which is free of charge and verified by the accuracy of lighting simulation programs, the International Commission on Illumination (CIE) distributed in technical report CIE 171:2006.

Three scenarios for glazing ratio with two alternatives for the different dimensions of windows are applied to the model. Two of glazing ratio scenarios have two altered sizes; the other situation has only one option. The models are adopted from Kutlu et al. study (2012).

Since the study is related to the school building, the working periods and hours of the national academic calendar are considered to define the critical days and hours. Schools are closed during summer period so winter solstice and spring equinox, March 20 and December 21, are selected as essential days while 10:00 am and 2:00 pm are defined as critical hours of the study. The sky for 20 of March is assumed as clear sky while it is supposed to be the overcast sky on 21 of December. Besides, all of the daylighting simulation are calculated from the work area of students and teacher that has a 0.80m height from the floor. The analyses are based on visual comfort calculation that will be led to improve their performance.

### **Model S1**

The glazing ratio is 30%. Total Windows area is 8.15m<sup>2</sup>. There are two alternatives defined for this window wall ratio. The first proposed window dimension is 4.80m x 1.70m that are a horizontal window with a sill height of equal to 0.90m. The second option includes three windows, which are the same dimensions. The sill heights are 0.90m. The second alternative windows' dimensions are 1.55m x 1.70m.

### **Model S2**

In this model, the transparency ratio is 40%. The total Windows area is 10.87m<sup>2</sup>. There are two options defined for this window wall ratio. The first recommended window dimension is

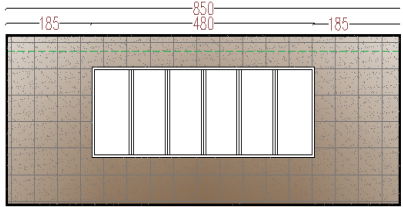
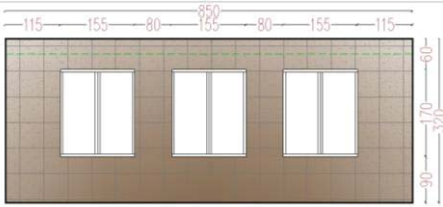
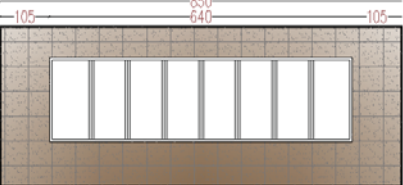
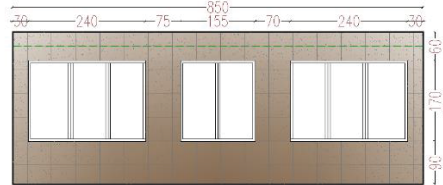
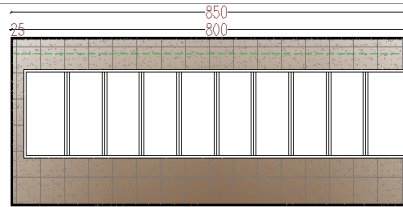


6.40m x 1.70m. This window is a horizontal window. The second choice includes three windows, which are not of the same dimensions. All of the windows' sill heights are 0.90m. The other option has two sizes of windows, the first one is 1.55m x 1.70m, and the next one is 2.43m x 1.70m.

### Model S3

The glazed area accounts for 50% of the wall area. The total Window area is 13.60m<sup>2</sup>. There is one alternative defined for this window wall ratio because there is not enough vacant place to add a different dimension on the envelope. The proposed window dimension is 8.00m x 1.70m. The sill height is 0.90m. As the façade is of this classroom is 27.16m<sup>2</sup>. Table 1 shows the recommended alternatives for a window organisations and sizes.

Table 1. Recommended alternative design for windows of example classrooms on East and West facade

	Windows area	Glazing ratio %	Alternative Design 1	Alternative Design 2
S1	8.15 m <sup>2</sup>	30%		
S2	10.87 m <sup>2</sup>	40%		
S3	13.60 m <sup>2</sup>	50%		

### Description of the Case Study Building

The case study primary school building is designed to be located in Eskisehir-Turkey. The Latitude and Longitude for Eskisehir are 39.46° N and 30.31° E respectively. It has a cold and dry climate. The building has 20 classrooms with the capacity of 600 students. It has 22m height and 1754.75 m<sup>2</sup> floor area while the total area is 6719.45 m<sup>2</sup>. The school has five stories including the basement floor, ground floor, and three typical floors.

The primary school is occupied on weekdays between 08:00 am and 17:00 pm. The total glazing surface area of is 1058.42 m<sup>2</sup> and transparency ratio is 20%. Glazing components of the building consist of aluminium frames. Solar Heat Gain Coefficient (SHGC) and Visible Transmittance are 0.81 and 0.73 respectively.

Occupancy time for primary schools in Turkey includes fall semester and spring semester. The school opens at fall semester from 15 September until 31 January and at spring semester from 15 February till 15 June. Figure 1 and Figure 2 indicate the geometry and ground floor plan of the case study building.

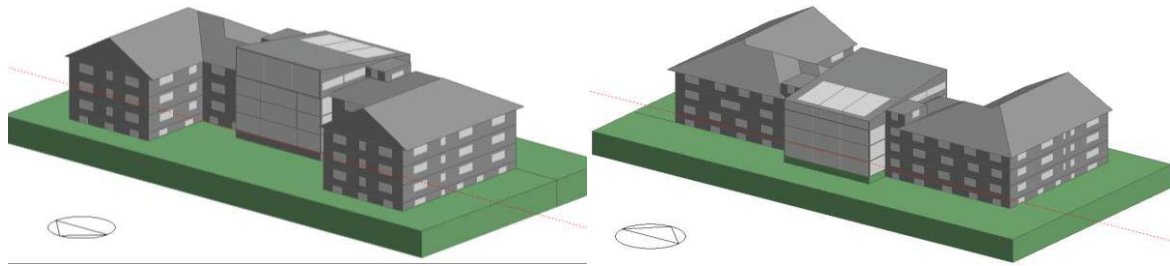


Figure1. Geometry of the case study building

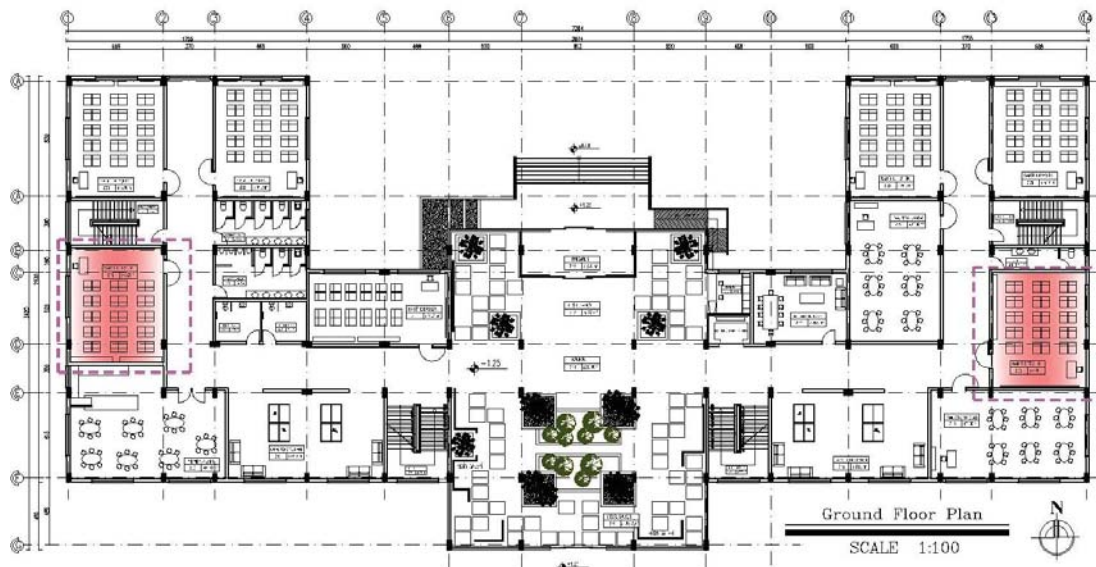


Figure 2. Ground floor plan of the primary school building in Eskisehir

The selected example of classrooms from different orientations (East and West) consider a typical classroom (8.60 x 7.20 m) with a minimum height of 2.9 m. The position of the selected class from East and West sides are shown in figure 2. The classroom is expected to be used for general teaching activities including reading, writing and craftwork. The class has a formal teaching position together with a whiteboard. The main aim is to utilise daylight in the classroom for most of the occupancy times and artificial lighting to be used when the daylight is not adequate. The following scheme shows the plan, section from the middle of classroom and facade of the selected class in Figure 3.

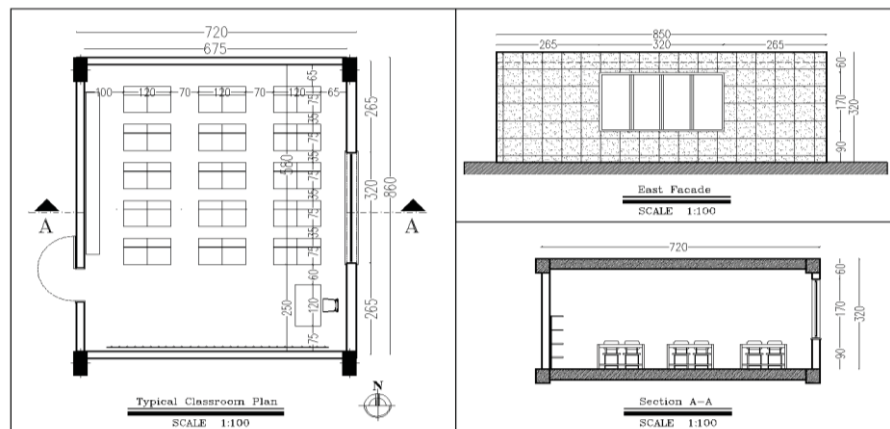


Figure 3. Plan, elevation and section of classroom chosen through to the East elevation.

The reflectivity of the surfaces was set as follows:

- Ceiling reflectivity: 80%,
- Sidewall reflectivity: 60%,
- Floor reflectivity: 20%,

The transmittance of the glazing was set to 73%.

The sky types used in the simulations were CIE Overcast Sky and CIE Clear Sky with Sun.

## Results and Discussion

To assess the daylight status in the classrooms, where the sufficiency of daylight is the primary target, the daylight factor, and illuminance level was considered as the most proper parameters for demonstrating the quantity of admitted daylight and the efficiency of the daylighting design. Table 2 and Table 3 show Mean Daylight Factor together with average, minimum, and maximum daylight illuminance level (lux) of different scenarios on March 20 at 10:00 am and 2:00 pm under the Clear Sky and Overcast Sky. Overcast sky condition applied in daylight factor calculations.

According to the Building Bulletin 90 (1999), values of daylight factor ranging from 4% to 5% is reported as satisfactory for school occupants. Consequently, by looking at daylight factor values, the glazing ratio of 50 % is acceptable in both directions in all two days.

Table 2. Mean daylight factor, minimum, average and maximum daylight illuminance level (lux) of different scenarios at 20 of March at 10:00 am and 2:00 pm with clear sky

No.	Alt.	Direction of windows	Transparency Ratio (%)	Mean Daylight Factor (%)	Daylight Illuminance Level (LUX)					
					10:00 AM			14:00 PM		
					Minimum	Average	Maximum	Minimum	Average	Maximum
P1	Exist.	EAST	20	1.7	52.8	2727	41961	17.8	290	1769
P2	S1-1	EAST	30	2.1	62.8	3430	34408	25.8	362	1612
P3	S1-2	EAST	30	1.6	51.7	2646	32470	19.2	281	1080
P4	S2-1	EAST	40	3.3	102	5674	43723	42.5	599	2106
P5	S2-2	EAST	40	2.1	70.1	3761	36960	36.1	404	1409
P6	S3	EAST	50	3.8	124	6830	47211	52.5	727	2209
P7	Exist.	WEST	20	1.7	18.2	285	1726	34.9	2486	46767
P8	S1-1	WEST	30	2.1	27.8	356	1568	48	3163	38430
P9	S1-2	WEST	30	1.6	21.3	275	1050	36.4	2401	36339
P10	S2-1	WEST	40	3.3	44.4	589	2043	81.8	5233	47537
P11	S2-2	WEST	40	2.2	37.3	398	1358	62.1	3481	37711
P12	S3	WEST	50	3.8	54.5	715	2129	105	6354	47883

Table 3. Mean daylight factor, minimum, average and maximum daylight illuminance level (lux) of different scenarios at 21 of December at 10:00 am and 2:00 pm with overcast sky

No.	Alt.	Direction of windows	Transparency Ratio (%)	Mean Daylight Factor (%)	Daylight Illuminance (LUX)					
					10:00 AM			14:00 PM		
					Minimum	Average	Maximum	Minimum	Average	Maximum
P1	Exist.	EAST	20	1.7	6.08	167	1603	5.88	161	1549
P2	S1-1	EAST	30	2.1	7.58	208	1438	7.33	201	1390
P3	S1-2	EAST	30	1.6	6.94	165	1024	7.09	159	990
P4	S2-1	EAST	40	3.3	14	345	1844	13.5	333	1783
P5	S2-2	EAST	40	2.1	11.4	236	1236	11	228	1194
P6	S3	EAST	50	3.8	17.8	420	1889	17.2	406	1826
P7	Exist.	WEST	20	1.7	6.08	167	1603	5.88	161	1549
P8	S1-1	WEST	30	2.1	7.58	208	1438	7.33	201	1390
P9	S1-2	WEST	30	1.6	6.94	165	1024	7.09	159	990
P10	S2-1	WEST	40	3.3	14	345	1844	13.5	333	1783
P11	S2-2	WEST	40	2.2	11.4	236	1236	11	228	1194
P12	S3	WEST	50	3.8	17.8	420	1889	17.2	406	1826

Illuminance level to be adequate for general teaching spaces should not be less than 300 lux. Thus, at 20 of March at 10:00 a.m. average illuminance level with 20% window wall ratio, which is 2727 lux, is adequate for general teaching spaces if the classroom is oriented to the East. However, the illuminance level at 20 of March at 10:00 a.m. is not appropriate where the class is oriented to the West. To provide acceptable illuminance level for teaching at these hours, the occupants require artificial lighting.

In the East oriented classroom, the current situation and S1-2 have not acceptable levels of average daylight illuminance on 20 of March at 02:00 p.m. It is valid for West oriented classroom at 10:00 a.m. The classes with these statuses have lower than 300 Lux illumination level, which is the minimum requirement at teaching spaces.

Looking at the results of the simulation, the average daylight illuminance on December 21 at the Overcast sky, in most of the situations illuminance level is lower than 300 Lux. However, the scenarios S2-1 with 40% transparency ratio and S3 with 50% transparency ratio in both the East and West directions provide enough illuminance level for teaching.

Comparing the average daylight illuminance levels, by increasing glazing ratio the amount of illumination are exceeded. Despite this fact, there is a significant variation on a model with the same glazing ratio on first alternative and second alternative design for the windows. Average illuminance level at 20 of March at 10:00 a.m. in the East direction of S1-1 is 3430 Lux while it reaches to 2646 Lux in A1-2, which is equal to 22% reduction of illuminance.

From another point of view, on March 20 at 10:00 a.m. and 02:00 p.m., average illuminance level for all scenarios in the East and West directions respectively are so high, which causes to visual discomfort (direct glare) for occupants.

Moreover, in S1-1, the average illuminance level in the West direction at 10:00 a.m. on March 21 is 356 Lux, which is the adequate for teaching area according to Building Bulletin 90. By changing, windows models to the (S1-2) option average illuminance level reaches to 275 Lux that is 24.5% decrease of illuminance. Also, this reduction causes to utilise from artificial lighting in the classroom. (Figure 4)

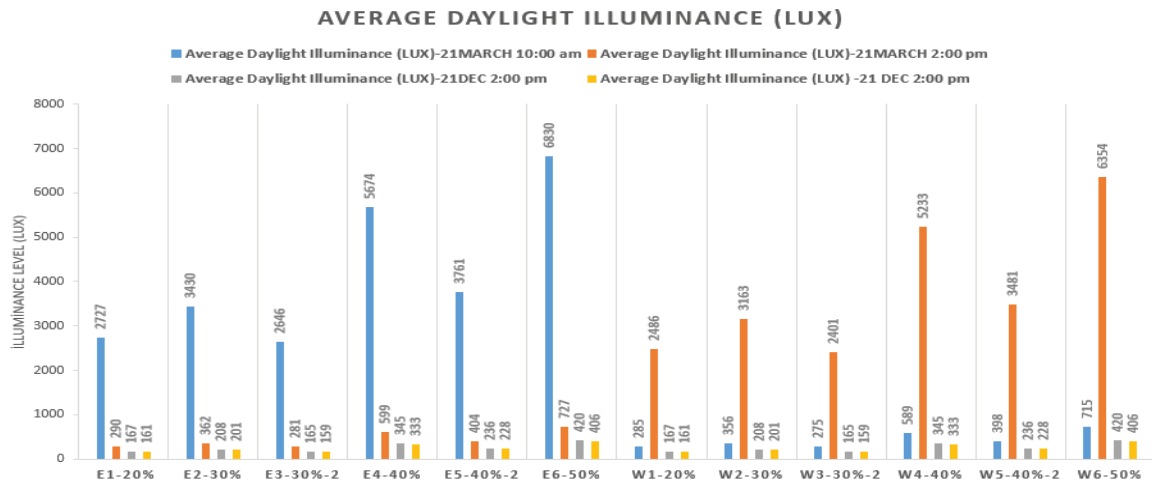


Figure 4. Average daylight illuminance (Lux) on the March 20 and December 21 at 10.00 a.m. and 2:00 p.m. on the Clear Sky and Overcast Sky respectively

As argued before minimum required level illuminance for the classroom is 300 Lux due to providing visual comfort to occupants. The illumination system in the classes should be satisfactory level to perform activities like reading and writing on the horizontal work plans and vertical whiteboard on the walls. Figure 5 shows the plan of Illumination level distribution through the middle axis of the classroom in the 20 of March at 10.00 a.m. (Left) and 02.00 p.m. (Right) with a Clear sky in the East direction in the current situation (Glazing ratio equal to 20%).

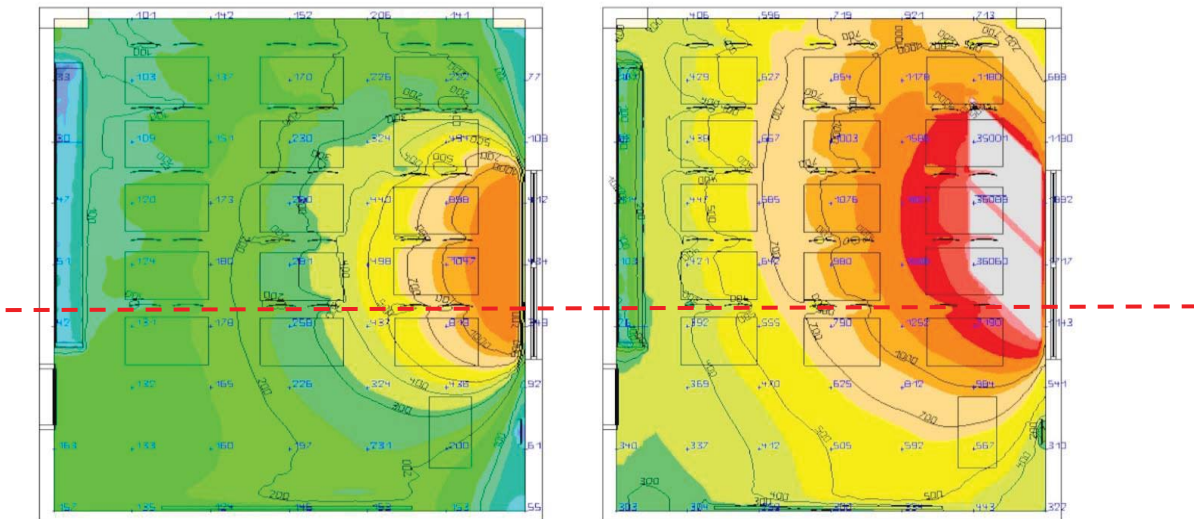


Figure 5. Illumination level distribution through the middle axis of the classroom on the March 20 at 10.00 a.m. (Left) and 02.00 p.m. (Right) in clear sky from East direction on existed situation (Glazing ratio 20%)

Figure 6 and Figure 7 represent illumination level distribution through the middle axis of the classrooms on the March 20 at 10.00 a.m. and 2:00 p.m. in the clear sky from East directions respectively.

Based on Figure 6, it is clear that (S1-2) 30% and (S2-2) 40% alternatives have fewer illuminance levels at a 1.1 m distance from windows by comparison to other scenarios. The main reason for this variation is locating of parts of the wall between windows in the middle of classes. The level of illuminance for all alternatives at 2.2 m distance from the windows reach almost at the same quantity. Therefore, the most variation of illuminance happens near to the windows.



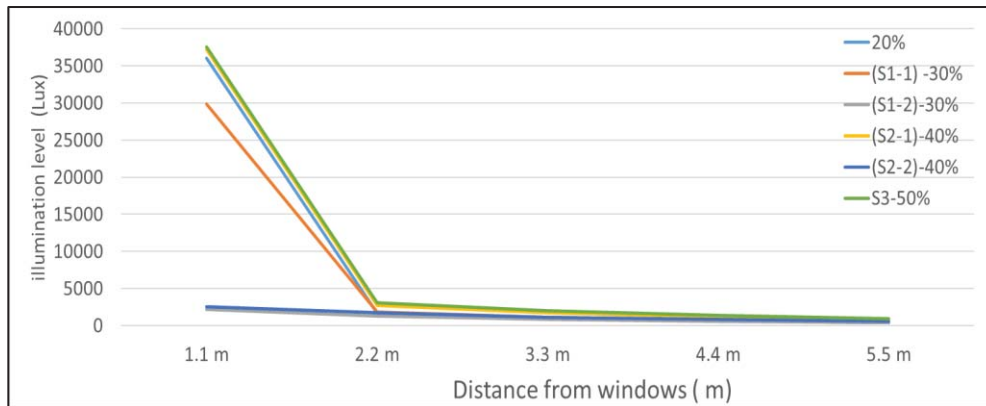


Figure 6. Illumination level distribution through the middle axis of the classroom on the March 20 at 10.00 a.m. in clear sky from East direction

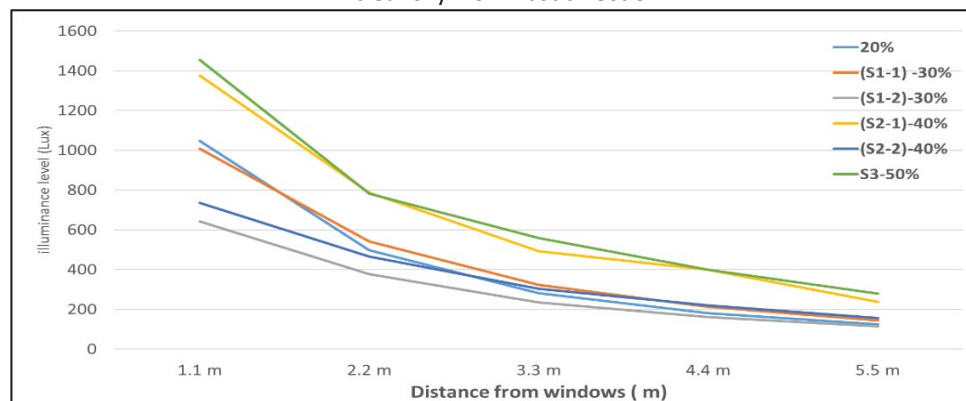


Figure 7. Illumination level distribution through the central axis of the classroom on the March 20 at 02:00 p.m. in clear sky from East direction

By regarding Figure 7, through the middle axis of the classroom on March 20 at 2:00 p.m. in the East direction illumination levels for all alternatives are adequate for writing and reading until the 2.2-meter distance from windows.

However, the illuminance level at a 3.3-meter distance from windows is not enough for alternative (S1-2) 30% glazing ratio and existing situation with 20% Transparency ratio. By analysing all options and current status, horizontal desk plans Illumination level at 5.5-meter distance from windows at 2:00 p.m. on March 20 in the East direction is not enough for teaching areas which are lower than 300 Lux. (Figure 7)

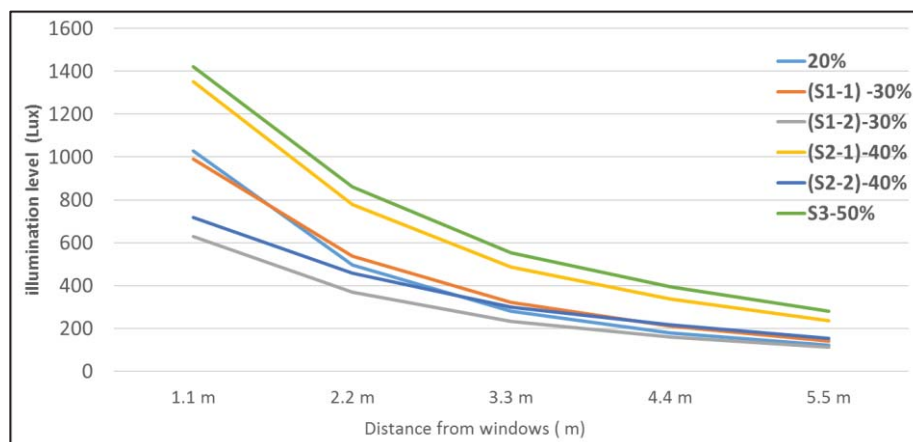


Figure 8. Illumination level distribution through the middle axis of the classroom on the March 20 at 10.00 a.m. in clear sky from West direction



Figure 8 represents illumination level distributed from the West direction on the horizontal work plans in the middle axis of the classroom, on 20 of March at 10.00 a.m., in the clear sky, at a 1.1-meter distance from windows are adequate for studying in all alternatives. However, illumination level for desk plans at 3.3 m, 4.4 m, and 5.5 m distance from windows are not satisfactory levels for students.

On the contrary, Figure 9 displays all alternatives illumination levels distributed from the West direction on the horizontal work plans in the middle axis of the classroom, on 20 of March at 02.00 p.m., in the clear sky are adequate for reading and writing of students.

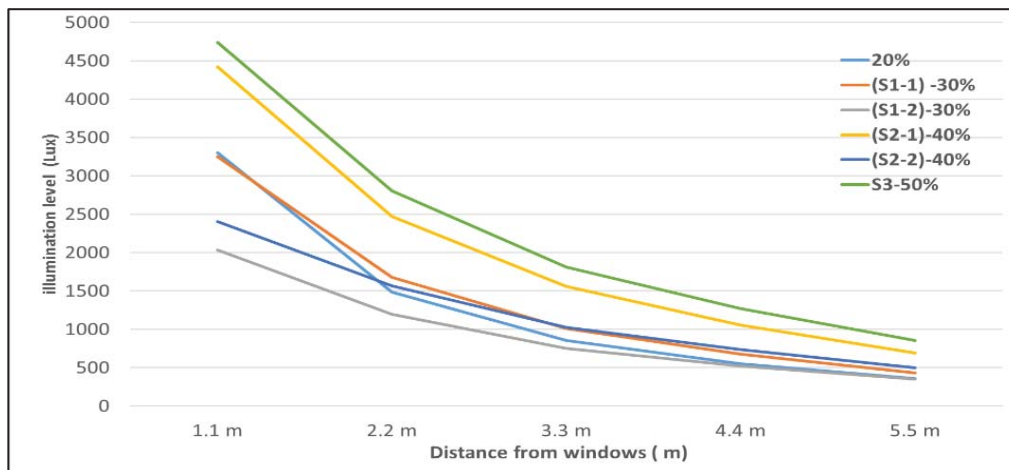


Figure 9. Illumination level distribution through the middle axis of the classroom on the March 20 at 02:00 p.m. in clear sky from West direction

To well day-lit the classroom, the average daylight factor of 4-5% is required by BB90 (1999), and the minimum daylight factor for the classroom should be 2% (Lechner, 2012; Al-Khatatbeh, 2017). Usage of artificial lighting will be the design solution to meet the requirement. Figure 10 shows the Mean Daylight Factor (%) through the middle axis of the East and West Direction classrooms on March 20.

By comparing Daylight Factors (%) the second row of desk plans on March 20 through the axis from the middle of the windows, daylight factor at a 0.65-meter distance from the windows is sufficient for teaching by regarding the guidelines. However, after 3.65-meter, work plane's daylight factor is lower than 4% hence there are not well daylit these work plans.

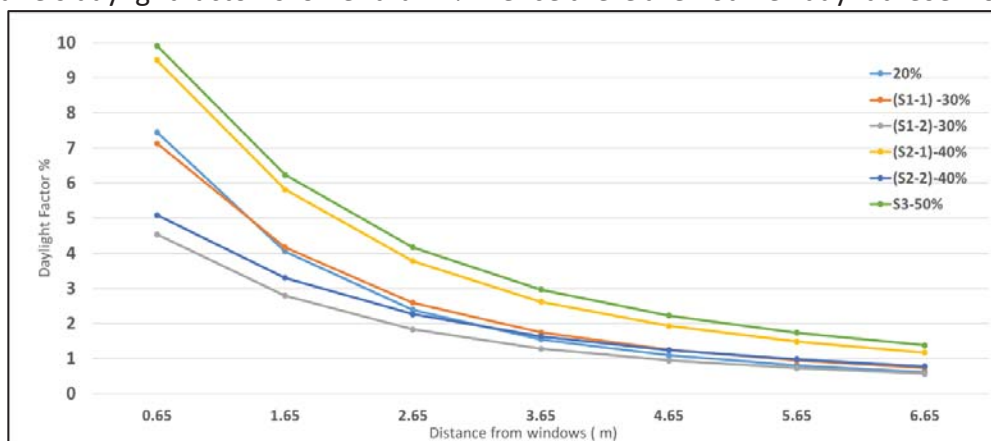


Figure 10. Daylight factor (%) through the middle axis of the East and West Direction classrooms at March 20.

Illuminance level to be adequate for general teaching spaces should not be less than 300 lux. Also, daylight factor ranging from 4% to 5% is reported as satisfactory for pupils. On 20 of March at 10:00 a.m. average illuminance level with 20% window wall ratio is 2727 lux, which is adequate for general teaching spaces where the classroom is oriented to the East. However, the illuminance level at 10:00 a.m. is not appropriate when the class is oriented to the West. To provide acceptable illuminance level for teaching at these hours, the occupants require artificial lighting. In Table 4, the measures that have more than 300 Lux illuminance level are shown in Grey, and the actions that have ranged from 4% to 5% daylight factor are indicated in Green.

Table 4. Evaluation of average daylight illuminance level (lux) and daylight factor of different scenarios on March 20 and December 21 at 10:00 a.m. and 2:00 p.m.

No.	Direction	20th March- Clear Sky		21st December- Overcast Sky		Mean Daylight Factor (%)
		10:00 AM	14:00 PM	10:00 AM	14:00 PM	
		Daylight Illuminance (LUX)	Daylight Illuminance (LUX)	Daylight Illuminance (LUX)	Daylight Illuminance (LUX)	
P1	EAST	2727	290	167	161	1.7
P2	EAST	3430	362	208	201	2.1
P3	EAST	2646	281	165	159	1.6
P4	EAST	5674	599	345	333	3.3
P5	EAST	3761	404	236	228	2.1
P6	EAST	6830	727	420	406	3.83 ~ 4
P7	WEST	285	2486	167	161	1.7
P8	WEST	356	3163	208	201	2.1
P9	WEST	275	2401	165	159	1.6
P10	WEST	589	5233	345	333	3.3
P11	WEST	398	3481	236	228	2.2
P12	WEST	715	6354	420	406	3.83 ~ 4

## Conclusion

The primary purpose of using natural lighting in schools is not only increasing students and quality of illumination but also reducing the artificial energy loads and energy costs. Visual performance plays a critical role in energy efficient lighting design. By focusing on the impression of different transparency ratios and window directions of sample classrooms, visual comfort of pupils and instructors are evaluated regarding average illuminance levels and daylight factors on two days and hours. A similar analysis should be conducted in the early design stage to decide proper transparency ratio and window combinations.

By analysing the results of simulations, in 20 of March at 10:00 a.m., in the east oriented classrooms, in all cases the daylight illuminance level is enough to provide the satisfaction level independently. Also, at 02:00 p.m., in the west oriented classrooms, the daylight level is enough to provide an acceptable level for students and teachers. Hence, it is not necessary to use artificial light in these circumstances.

Despite having same glazing ratios in model 1 and 2, the second model provides lower illuminance levels, which is not appropriate for these classrooms. As a result, demand for artificial lighting has exceeded in some of the scenarios. However, visual comfort for students

and instructors in the classes oriented to the East and West have not been provided in the current situation, S1-1, S1-2, and S2-2 alternatives, on December 21 at 10:00 a.m. and 02:00 p.m.. Consequently, it is necessary to have artificial lighting in December. Moreover, by increasing glazing ratio requiring for daylighting, other factors like the proper design of windows and locations of the other crucial items for getting appropriate illuminance levels should not be omitted.

Finally, it can be derived that the appropriate transparency ratio for East and West directions in Eskisehir is 50%. It should also be mentioned that in this study the focus was just on the illuminance thus thermal performance together with glare reduction arrangements were not taken into account. These issues are of high importance also and shouldn't be ignored. For thermal performance analysis, the whole building with designed HVAC system should be studied thoroughly, and proper shading devices should be utilised to reduce the glare. Considering the working hours of schools, the East direction is critic direction from glare problem point of view while the West direction is not very exposed to the glare problem.

## References

- Al-Katatbeh, B., Ma'bdeh S.N., (2017). *Improving visual comfort and energy efficiency in existing classrooms using passive daylighting techniques*, Energy Procedia, 136, pp. 102-108
- Delvaeye, R., Ryckaert, W., Stroobant, L., Hanselaer, P., Klein, R., Breesch, H. (2016). Analysis of energy savings of three daylight control systems in a school building by means of monitoring, Energy and Buildings, 127, pp. 969–979
- Edwards, L., Torcellini, P. (2002). *A Literature Review of the Effects of Natural Light on Building Occupants*, Colorado: U.S. National Renewable Energy Laboratory.
- Falken, A. (2012). *School Lighting Upgrades Save Money, Allowing Schools to Make Health and Achievement Promoting Repairs* [Online] U.S. Department of Education, Available at: <https://blog.ed.gov/2012/10/school-lighting-upgrades-save-money-allowing-schools-to-make-health-and-achievement-promoting-repairs/> [Accessed 08/09/2017].
- Kutlu, R., Yener, A., Manav, B., Küçükdoğu, M.S. (2012). *Daylight analysis and lighting energy management for schools in hot-temperate climates*, ITU Journal A/Z, VOL: 9, NO:1, pp. 149-164,
- Korsavia, S.S., Zomorodian, Z.S., Tahsildoost, M. (2016) *Visual comfort assessment of daylit and sunlit areas: A longitudinal field survey in classrooms in Kashan, Iran*, Energy and Buildings, 128, pp. 305–318
- Lechner, N. (2012). *Heating, Cooling, Lighting: Sustainable Design Methods for Architects*, J. Wiley & Sons.
- Meresi, A. (2016). Evaluating daylight performance of light shelves combined with external blinds in south-facing classrooms in Athens, Greece, Energy and Buildings, 116, pp. 190–205
- Michael, A., Heracleous, C. (2017) Assessment of natural lighting performance and visual comfort of educational architecture in Southern Europe: The case of typical educational school premises in Cyprus, Energy and Buildings, 140, pp. 443–457
- Penny, J. (2012). *School Lights* [Online] Buildings, Available at: <http://www.buildings.com/article-details/articleid/13463/title/school-lights.asp> [Accessed 04/02/2016].
- RR Donnelley (2007). *School Design: Optimising the Internal Environment Building Our Future: Scotland's School Estate*, Edinburgh: Scottish Executive
- Sicurella, F. , Evola, G., Wurtz E. (2012). A statistical approach for the evaluation of thermal and visual comfort in free-running buildings, Energy and Buildings, 47, pp. 402–410
- Turkish Ministry of National Education (2015). *National Education Statistics-Formal Education-2015/2016*, Ankara: National Education Strategy Development Presidency.
- UK Department for Education and Employment (1999). *Lighting Design for Schools*. Building Bulletin 90, London: The Stationery Office.
- UK Department for Education and Skills (2003). *Guidelines for Environmental Design in Schools*, London: School Building and Design Unit.
- UKessay (2015). *Effects of Light on Internal Body Systems Psychology* [Online] Available at: <https://www.ukessays.com/essays/psychology/effects-of-light-on-internal-body-systems-psychology-essay.php> [Accessed 05/09/2017].

# Systematic Literature Review: Customer's Requirements for Social Housing Design

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**Abstract:** The high demand of housing units (HU) in Brazil, result of housing deficit, coupled with the need to deliver low cost HU's and with minimum requirements of quality, that can promote comfort, health and safety to users (final client), form a complex and challenging scenario to professionals related to the built environment. This article is inserted in the context, since it deals with the partial results of a project of scientific initiation entitled: quality of social housing design (SHD) in the municipality of Maraba, state of Para, in the Brazilian Amazon: customer's requirements. In this sense, the objective of the article is to identify the quality requirements of the SHD, through systematic literature review (SLR). For this, the SLR based on the 07 steps suggested by (Camargo and Morandi, 2015): Definition of the central theme and conceptual framework; aggregative or configurative revision; choice of work team; search strategy; selection of data; research of, eligibility and codification; synthesis of results. It was analysed 22 published studies related to the research problem and it was possible to identify 15 requirements. The SLR results were useful for the characterization of SHD, in addition to offering guidance subsidies for the search string, insofar as the theoretical information served as a reference to analyse the projects implemented, potentials and failures. Finally, the work contributes to the identification of some gaps in the theme and, consequently, the opening of opportunities for new research.

**Keywords:** Social Housing, Requirements, Customer

## Introduction

It is well known that a feedback on building performance is usually obtained through post-occupancy evaluation. For this reason, problems associated to the customers non-satisfaction generally is detected only when the project is finished, which results on constructive interventions as soon as the house is occupied. Due to structural modifications, damages on the quality of the building appear earlier than the expected (Brandão, 2011). So far, only a few critical solutions were made about this problem. Considering this aspect, a solution to housing units based on the customer's needs has been explored. The principle of this methodology is based on the management of customer's requirements, in social housing design (SHD).

According to (Kamara et al, 2000), requirements can be defined as functions, attributes, and other characteristics of a product or service. (Miron, 2002) infers that during the development of any project, the client's solicitation must be captured and introduced in the design; from this step, the requirement assumes the form of a construction attribute. In some cases, client's requirement has been obtained through structured interviews, such as those made by (Alaghbari et al, 2010) (Baldauf et al, 2013) and (Kassela et al, 2017). Also, through post-occupation evaluation, as stated by (Aragão and Hirota, 2016), (Conceição et al, 2015) and (Orihuela and Orihuela, 2014).

Customer's requirements involve a large amount of qualitative information (Kivinieme, 2005). In accordance with (Kamara et al, 1999), the requirement process includes the identification, analysis and it is translation. Translation means (Lima et al, 2011) to change the customer's requirements into a design requirement. The identification of a requirement includes the stakeholders' definition, design attributes, and performance criteria. (Baldauf et

al, 2013), advises that the best requirement comprehension passes through the process of it is deployment in many levels; it makes possible the attribute final definition.

Based on those concepts, *Minha Casa Minha Vida* Program (MCMVP) can be used as an example, once it comprises an interface between the Social Housing Design and Customer's Requirements. This program was created in 2009 by the Brazilian Government in order to reduce the Brazilian housing deficit. Since the begin, MCMVP has been a target to many researchers (Granja et al, 2009); (Miron and Formoso, 2010); (brandão, 2011); (Bonatto et al, 2011); (Lima et al, 2011); (Baldauf et al, 2013); (Ruiz et al. 2014); (Conceição et al, 2015); (Monteiro et al, 2015); (Aragão and Hirota, 2016), interested on the development of a product (housing units) with quality, added value, and that can be able to provide comfort and well-being to the customer.

Such an evaluation of customer's needs has rarely been extended to the social housing, the main idea of this paper is to identify the customer's requirements on social housing design (SHD), using the systematic literature review (SLR). This paper is a part of a research project called: quality of social housing design (SHD) in the municipality of Maraba, Brazilian Amazon. In this sense, it is necessary to study a better way to understand the method and technical concepts about customer's requirements in order to deliberate actions for sequential steps. For this reason, the concept of systematic literature review was used.

## **Research Methodology**

### ***Systematic Literature Review - SLR***

(Kitchenham, 2004) defines systematic literature review SLR as: "the identifying, evaluating and interpreting all available research relevant to a particular research question, or topic area, or phenomenon of interest". Generally, a preliminary study is based on individual data that can be used as an input to SLR. The secondary study is constituted by the own SLR (Kitchenham, 2004). According to (Morandi and Camargo, 2015): "The secondary studies are used to map, to find, to evaluate critically, to consolidate, and to aggregate the results of a preliminary study about a specific research topic".

The word "systematic" refers to the way a research can be led. "It is related, according to the explanatory method, to the plan, to the responsibly, and to the justifiability, in order to allow the research to be unbiased, rigorous, auditable, replicable and updatable." (Morandi and Camargo, 2015).

Concerning the justifications for the using of an RSL, (Kitchenham, 2004), point toward: (a) to summarize the evidences about the benefits and limitations of a subject; (b) Identify any gaps on the specific knowledge in order to suggest a research opportunity; (c) to provide a conceptual framework.

There are many ways to conduct a SLR, among it, stands out the proposal of (Morandi and Camargo, 2015). The proposed method consists in 07 steps: choice of the main theme and the conceptual framework; aggregative or configurative review; choice of work team; search strategy; data selection; search, eligibility and codification; summarize results.

Configurative review explores open and oriented issues of the generation of qualitative data, through the exploration of more heterogeneous primary studies. On the other hand, the aggregative review uses a more homogeneous primary study, mostly involving qualitative data; it is orientated by testing a theory (closed questions) from the collection of empirical observations.



According to the steps proposed by (Morandi and Camargo, 2015), in this work, the method was chosen considering the main idea, social housing, focused on the study of customer's requirements in a project of quality of social housing design (SHD).

Figure 1 presents an example of a social house located at Ponta de Pedra, archipelago of Marajo, Brazilian Amazon: (a) frontage project; (b) layout; (c) the construction final phase.

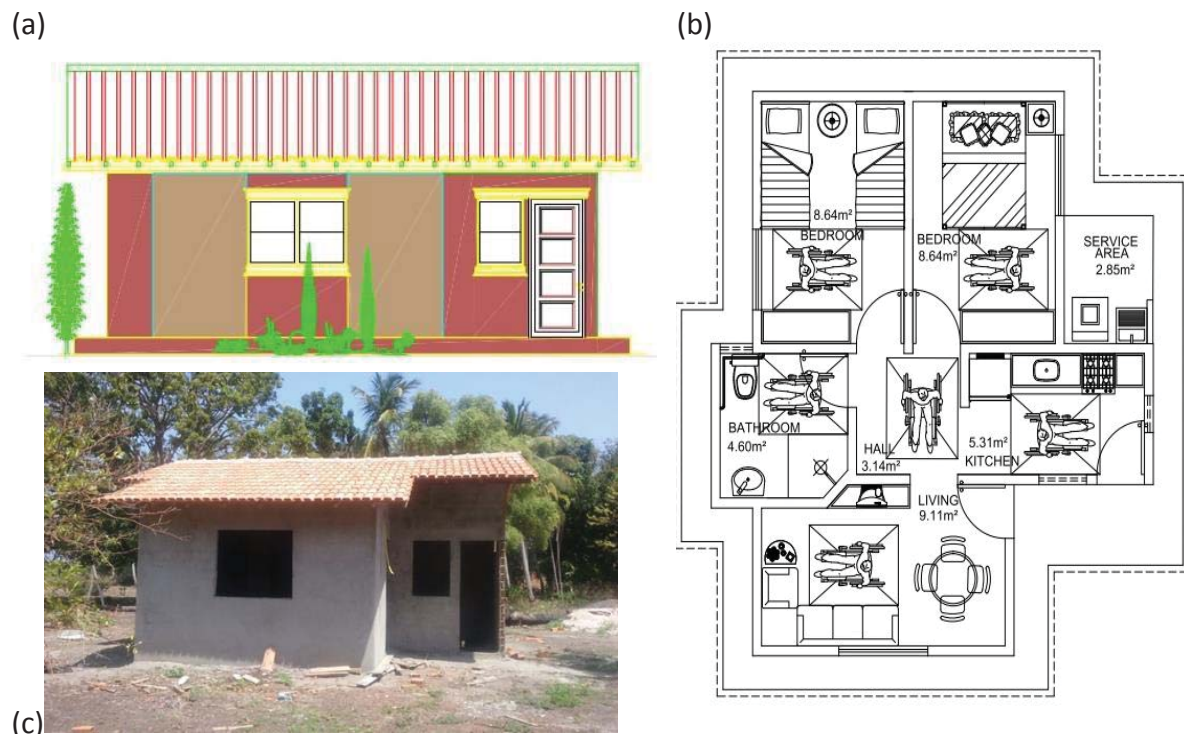


Figure 1: Example of a social house unit located at Ponta de Pedra, archipelago of Marajo, Brazilian Amazon, (a) frontage project; (b) layout; (c) the construction final phase.

The conceptual framework adopted has restrictions, therefore, the framework contemplates the keywords considered relevant to the theme. Furthermore, by definition, the review was characterized as configurative; from the preliminary results, it was extracted the qualitative data, which was analyzed throughout the study. The work team was selected at the begin of the project conform indicated by (Camargo and Morandi, 2015); the team work was composed by 03 professors and 02 undergraduate students in Civil Engineering.

In terms of strategy, were considered 03 renowned databases that can be accessed by almost all universities around the world: Scielo, Scopus, and Web of Science. The search terms chosen were: requirements; social housing; design; customer; and construction. For the bias minimization, the exact words were used with the Boolean operators, considering order, word, and operators. In addition, the technique called truncation was used, which consists in the use of the symbol (\*), allowing the symbol's predecessor root to assume different terminologies, improving search efficiency. Table 1 summarizes the methodology used during the research step.

Parameters as such as search, eligibility, and codification, corresponds to operationalization. In each database, the Boolean operators were imputed. On filtering information, articles from journals and conferences were considered. There was no restriction on time factor; it was used all the papers inside this theme without year restriction, which means building a timeline for a specific topic. Zotero (an extension of Mozilla Firefox available free of charge) was used for data storage and management. The papers were



classified as the repetitions of publications, titles of the publications, abstracts, full reading, and quality analysis. From the synthesis of the data, it was presented a mapping of the subject including: number of publications found; publications by country; and publications per year.

Table 1. Electronic databases selected as search source.

Search	Sources	Boolean Operators
Search 01	Scielo, Scopus e Web of Science	Requirements* AND Social housing* AND Design* AND Construction
Search 02	Scielo, Scopus e Web of Science	Requirements* AND Social housing* AND Design
Search 03	Scielo, Scopus e Web of Science	Requirements* AND Social housing* AND Customer
Search 04	Scielo, Scopus e Web of Science	Requirements* AND Social housing* AND Design* AND Customer* AND construction

Not all publications were tracked by the 04 searches indicated on table 1, due to this limitation, the backward and forward procedures were used. Backward procedure considers the references cited on the papers used, and forward seeks new studies that have cited the document already selected, in order to track new publications.

## Results and Discussions

### *Bibliometric Aspects*

Bibliometric aspects involve the results obtained during a specific search. In this case, it is related to the numbers of papers published, authors, journals, year of publication, etc., which has some relation with the theme of interest, social housing design and it is customer's requirements. Table 2, summarizes the results of the general search (Web of Science, Scopus, Scielo), as well as the filtering process (search criteria). Concerning the found papers, it was obtained 106 publications from Web of Science, 252 from Scopus, 14 from Scielo, and 10 using the backward e forward proceedings, totalizing 382 publications.

Table 2. Results based on the source search (Web of Science, Scopus, Scielo).

Search data	Web of Science	Scopus	Scielo
Search 01	21	62	5
Search 02	78	167	9
Search 03	6	19	0
Search 04	1	4	0
Publications found from electronic databases	106	252	14
	372		
Backward and forward method	10		
Total papers found	382		

A simple methodology presented in Figure 2 summarizes the steps used during the systematic literature review (SLR), as well as the filters used in each part of the SLR.

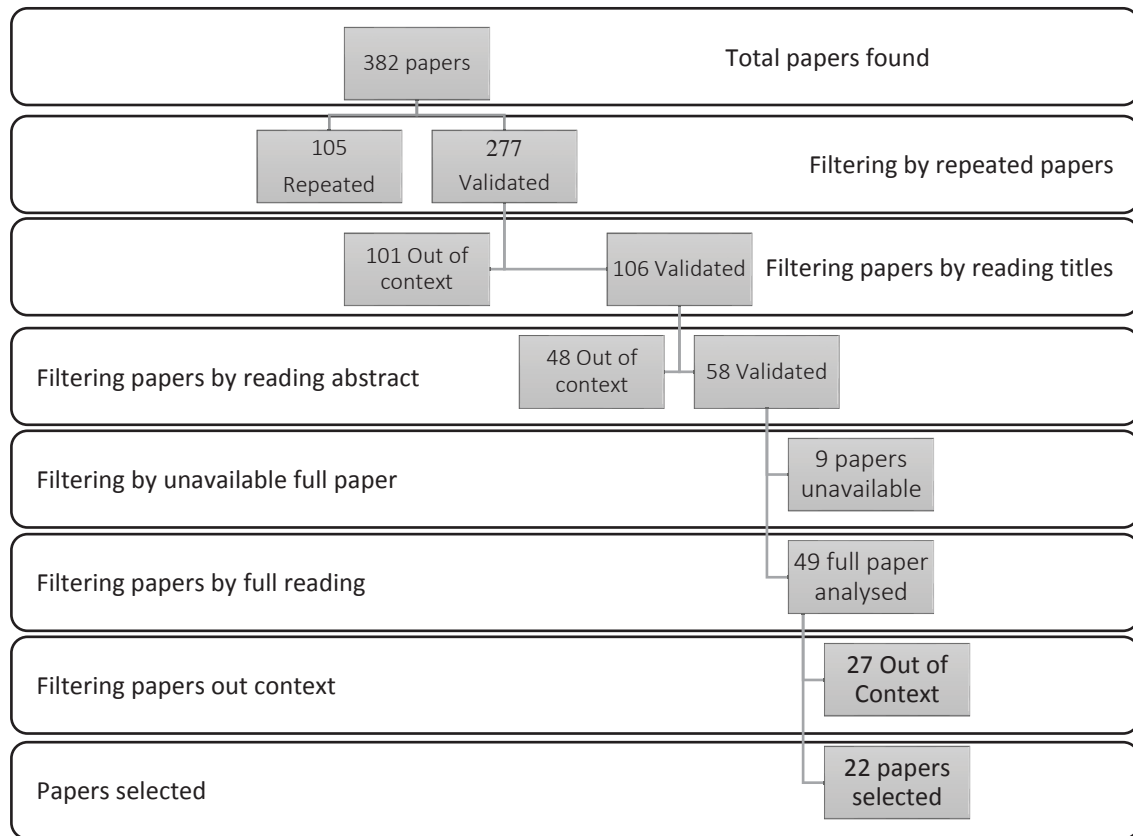


Figure 2. Steps used during the systematic literature review (SLR)

Figure 2 shows the results obtained by using the specific filters defined according to the project. The criteria used in the filtering were: exclusion by repeated papers, title reading, summary reading, accessibility to the full paper, full reading, and quality analysis, the final number is 22 published works on the indexed journals, approximately 6% of all publications (22 of 382). As it can be seen (Figure 3), considering the concerns with the client on social housing construction, predominantly researchers from Brazil were found. In addition, there are publications from Chile and Peru, 01 publication each. From the European continent, there are 02 publications from the United Kingdom. From Africa, there were 02 papers from South Africa. The Asian continent contributed with 02 papers, one from China and one from Yemen.

The indexed journals used are: Ambiente Construído; Gestão e Tecnologia de Projetos; International Journal of Housing Markets and Analysis; Journal of Construction in Developing Countries; Building Research and Information; The TQM Journal; Habitat International; Product Development and Design Management; Procedia Engineering; Architectural Engineering and Design Management; Built Environment Project and Asset Management; Frontiers of Architectural Research; Construction Innovation. Still on publications includes the repository of dissertations and theses of the Federal University of Rio Grande do Sul.

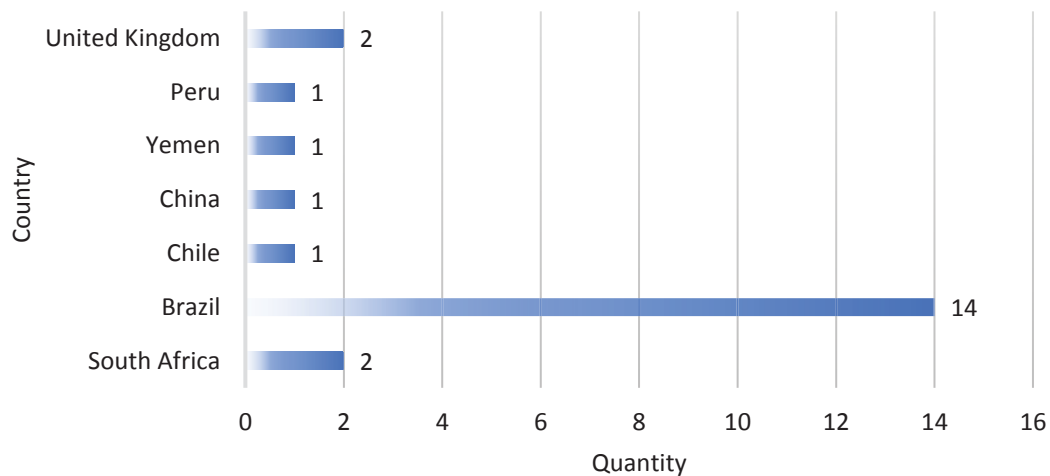


Figure 3. Number of publications per country.

Another extract obtained corresponds to the year of publication. As shown in Figure 4, between 2002 and 2009 the number of publications remained constant, with only 01 publication. The three papers published in 2010 have indicated an improvement, what was confirmed in 2011 with 07 publications, the highest in the series.

Some institutions achieved more than one publication. Federal University of Rio Grande do Sul had published 08 papers; University of Campinas had published 02 papers; and from University of Londrina it was found 02 papers. Considering a repetition of each author among publications: Miron contributed with 07 papers; 05 contributions from Formoso; 03 from Granja; and Kowaltowski has published 03 papers as well.

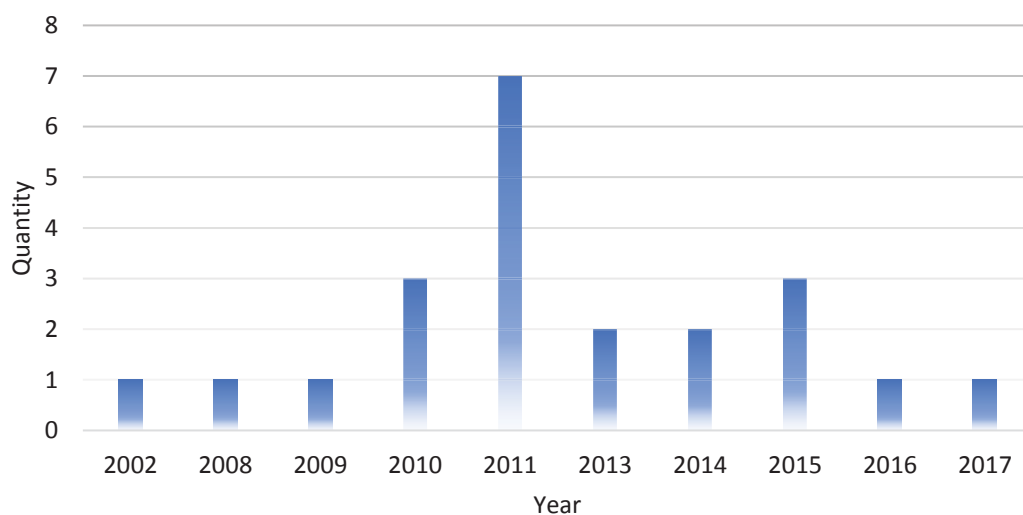


Figure 4. Publications per year.

### ***Specific Information – Customer's requirements***

Methodological proceedings for requirements identification was based on structured interviews with stakeholders; 80% of the requirements were identified by this methodology. As for the requirements raised through interviews, 49.9% were using questionnaires; 18.8% were obtained by using by post-occupation evaluation; and 31.3% by using Survey method.

As for the methods for systematizing the requirements: 20% were systematizing by QFD (Quality Function Deployment); 15% with a customer feedback (post-occupation evaluation); 30% by using with statistical inference techniques; 30% with a value analysis; and 5% were systematized through a building information modeling (BIM).

Obtained from an adaptation of (Kivinieme, 2005), the schematic details presented on Table 3 shows a relationship between the publishers, the customer requirements, as well as the amount, and the percentage of some requirements present in each article. Requirements are organized following the order: (a) conformity requirements (that includes location, space, and service); (b) performance requirements (indoor conditions, life cycle, security, adaptability, comfort, aesthetic, accessibility, and circulation); (c) environmental requirements (sustainability); (d) cost requirements (cost and price). Also, it was added the letter (e) system requirements that is included electrical systems and hydro sanitation facilities, Baldauf et al (2013).

#### *Conformity Requirements*

As for conformity, the location requirement was studied by the authors at 68% of the cases. This requirement involves the geographic location, in addition, it considers the public infrastructure. According to (Windapo and Goulding, 2013), the customer considers in this requirement the availability of transportation, the distance from the residence to the bus stop, the distance from residence to school, to work, to the city center, to hospitals and for culture, sports, and leisure support points.

On the other hand, the space requirement, according to 77% of authors, refers to the functionality of space. As stated by Orihuela and Orihuela, 2014, the dimensioning and distribution of the rooms must follow the costumer's request; it must be compatible with the human need. According to (Baldauf et al, 2013), the functionality of the spaces includes the areas, the dimensions of the housing units, as well as the furniture and equipment of the housing units and common use spaces. The author also considers functionality in terms of quality of construction, which encompasses space (construction of building components, floors, walls, frames, etc.). It is not considered the electrical and hydro-sanitary systems, although it has correlation with item functionality, these were treated in a separate requirement.

The service requirement (27%) indicates only tangible services (masonry elevation, coating, etc.) (Kivinieme, 2005).

#### *Performance Requirements*

Concerning performance requirements, the indoor condition was evidenced in 59% of the investigated papers. These criteria were based on the customer's request for the performance of the building in terms of lighting, climate, acoustics and room layout (Kivinieme, 2005). The arrangement of the room interfaces with the adaptability requirement was cited by the authors in 41% of the cases. This requirement is mentioned in terms of flexibility to expand the building; it was triggered by the analysis about the building adaptability considering the residents with special needs, a wheelchair, for example. The life cycle requirement (36%) was referenced in the articles, majority, for the requisition of maintenance of the building. The durability aspects of the building can be associated with shelf life, such as: durability of the structure; materials and components; durability conditions (Orihuela and Orihuela, 2014).

The security was the most expressive requirement, detected on 86% of the analyzed works. It was most evidenced in the sense of security of the residents and their patrimony. Security is strongly related to the location requirement (neighborhood security, street lighting, public transportation near the residences, etc.), for this reason, it is an information constantly required by the costumer before to receive the housing unit (HU). As well as after receiving the HU, this requirement is triggered by the type of constructive intervention performed by the user. Protective and seal fittings are introduced in the building (Orihuela and Orihuela, 2014) and (Miron, 2008), for example grilles, walls and alarm devices. (Granja et al, 2009), infers that security is directly related to the user's ability to control.

Comfort and aesthetic obtained the same percentage, 45%. The first one was mostly related to the privacy of the residents, and it has strongly relation with the indoor conditions. According to (Orihuela e Orihuela, 2014), comfort includes: thermoacoustic isolation, natural and artificial illumination; adequate ventilation in rooms; thermic comfort; ergonomic comfort during handling or operating equipment. Concerning aesthetics, it was considered the building appearance. Accessibility requirement was included in 9% of the analyzed papers. (Baldauf et al, 2013) considers that the customer requests a building with improvements that allow access to HU itself, as well as access to areas and equipment of common use. The circulation requirement was the less expressive (5%), which proves to be unusual on SHD. According to (Kivinieme, 2005), the circulation requirement can be to describe the circulation in the area or to describe the general system of circulation: lobby; corridor; stair; elevator; escalator; loading dock.

#### *Environmental Requirements*

Environmental requirement was observed in 36% of the considered papers, which is an expressive amount. It refers to the sustainability items previously related with SHD. According to (Orihuela e Orihuela, 2014), a SHD should contemplate the renewable energy, such as: solar energy, biomass, etc. The same authors imply that the SHD should cover the rainwater harvesting and reuse systems, sewage treatment systems (septic tank, anaerobic filter and sink), as well as green areas.

#### *Cost Requirements*

Cost requirements was found in 45% of the analyzed papers, mostly related to the building construction costs, proven by the nomenclatures founded on the papers – financial support, payment installments of a HU, etc. Although the SHD normally comes with a government support, the customers still consider the cost to as a preponderant factor in terms of requirements.

#### *System Requirements*

Electric and hydro-sanitary systems correspond to 27 and 23%, respectively. Both are related to the facilities in the building (Baldauf et al, 2013). This system makes an interface with the service requirement in the sense of quality of construction and final touch. Even with installations completed during the construction phase, the system remains active during the period of use of the HU. Therefore, the expectations of the user regarding these requirements, are related to the good operation and the durability of the installations.

Table 3. Relationship between the publishers, the customer requirements, as well as the amount, and the percentage of some requirements present in each article.

Requirements Authors	(a)			(b)								(c)	(d)	(e)	
	Location	Space	Service	Indoor conditions	Life cycle	Security	Adaptability	Comfort	Aesthetic	Accessibility	Circulation	Sustainability	Cost	Electrical systems	Hydro sanitation
(Alaghbari et al, 2010)		X				X	X	X		X			X		
(Aragão and Hirota, 2016)		X	X	X		X	X	X	X			X	X		
(Baldauf et al, 2013)	X	X		X		X			X	X	X			X	X
(Bonatto et al, 2011)	X			X		X		X	X						
(Brandão, 2011)	X	X	X		X		X							X	X
(Conceição et al, 2015)		X	X	X		X	X					X	X		
(Formoso et al, 2011)	X			X		X									
(Granja et al, 2009)	X	X		X	X	X		X	X				X		
(Gupta and Chandiwalla, 2010)		X		X			X	X				X		X	
(Jay and Boysen, 2011)	X	X		X		X									
(Kassela et al, 2017)		X			X	X									
(Kowaltowski and Granja, 2011)	X	X		X		X		X	X			X	X		
(Lima et al, 2011)	X	X	X	X		X		X					X	X	X
(Miron and Formoso, 2010)	X	X				X	X					X			
(Miron, 2002)	X			X	X	X	X		X				X		
(Miron, 2008)	X	X	X	X		X	X						X		
(Monteiro et al, 2015)	X	X	X			X		X	X						
(Orihuela and Orihuela, 2014)	X	X			X	X		X	X			X		X	X
(Pasquire et al, 2011)	X	X			X	X								X	X
(Ruiz et al, 2014)				X	X	X	X	X	X				X		
(Wang, 2015)					X				X			X	X		
(Windapo and Goulding, 2013)	X	X				X	X					X			
Quantity	15	17	6	13	8	19	9	10	10	2	1	8	10	6	5
Percentage (%)	68	77	27	59	36	86	41	45	45	9	5	36	45	27	23



## Conclusion

The main objective of this work was achieved using the RSL. Considering a social housing design (SHD), 15 customer's requirements were identified, as well as guiding the search sequence. Insofar as the theoretical information served as a reference to analyze user requirements, it makes possible to know the potentialities and failures.

With the set of requirements identified, it is evident the need to offer projects whose conceptions add favorable values to the social, historical and cultural reproduction of users. However, if it is observed the *modus operandi* of the design of social housing projects, in general, the projects have technical solutions with a diminutive or non-participation of the users. Therefore, it is necessary to modify the paradigm of low participation of the customer's contemplated with the housing of social interest; if the designer of a housing project programs can count on the customer's verification at the first step of the project, the adequacy with the reality and requirements of the customers could be done, avoiding future problems.

Finally, it was noticed the absence of research considering the users requirements that lives in the rural area. The 22 articles were focused on the capture and analyses of requirements in the urban area. This fact constitutes a knowledge gap and opens the opportunity for further research.

## References

- Alaghbari, W., Salim, A., Dola, K., Ali, A.A.A. (2011). Developing affordable housing design for low income in Sana'a, Yemen. *International Journal of Housing Markets and Analysis*, 4, 84–98.
- Aragão, D.L.L.J., Hirota, E.H. (2016). Sistematização de requisitos do usuário com o uso da Casa da Qualidade do QFD na etapa de concepção de unidades habitacionais de interesse social no âmbito do Programa Minha Casa, Minha Vida. *Ambiente Construído*, 16, 271–291.
- Baldauf, J.P., Formoso, C.T., Miron, L.I.G. (2013). Modelagem de requisitos de clientes de empreendimentos habitacionais de interesse social com o uso de BIM. *Ambiente Construído*, 13, 177–195.
- Bonato, F.S., Miron, L.I.G., Formoso, C.T. (2011). Avaliação de empreendimentos habitacionais de interesse social com base na hierarquia de valor percebido pelo usuário. *Ambiente Construído*, 11, 67–83.
- Brandão, D.Q. (2011). Disposições técnicas e diretrizes para projeto de habitações sociais evolutivas. *Ambiente Construído*, 11, 73–96.
- Conceição, P.A., Imai, C., Urbano, M.R. (2015). Captura e hierarquização de requisitos do cliente de habitação de interesse social a partir da avaliação pós-ocupação e da técnica de preferência declarada. *Gestão & Tecnologia de Projetos*, 10, 79–98.
- Formoso, C.T., Leite, F., Miron, L.I.G. (2011). Client Requirements Management in Social Housing: A Case Study on the Residential Leasing Program in Brazil. *Journal of Construction in Developing Countries*, 16, 47–67.
- Granja, A.D., Kowaltowski, D.C.C.K., Pina, S.A.M.G., Fontanini, P.S.P., Barros, L., Paoli, D. de, Jacomit, A.M., Maçans, R.M.R. (2009). A natureza do valor desejado na habitação social. *Ambiente Construído*, 9, 87–103.
- Gupta, R., Chandiwalla, S. (2010). Understanding occupants: feedback techniques for large-scale low-carbon domestic refurbishments. *Building Research & Information*, 38, 530–548.
- Jay, I., Bowen, P. (2011). What residents value in low-cost housing schemes: Some South African concepts. *Building Research and Information*, 39, 574–588.
- Kamara, J.M., Anumba, C.J., Evbuomwan, N.F.O. (1999). Client Requirements Processing in Construction: A New Approach Using QFD. *Journal of Architectural Engineering*, 5, 8–15.
- Kassela, K., Papalex, M., Bamford, D. (2017). Applying quality function deployment to social housing? *TQM Journal*, 29, 422–436.
- Kiviniemi, A., 2005. Requirements management interface to building product models. PhD. Stanford University.
- Kowaltowski, D.C.C.K., Granja, A.D. (2011). The concept of desired value as a stimulus for change in social housing in Brazil. *Habitat International*, 35, 435–446.
- Lima, L.P., Formoso, C.T., Echeveste, M.E.S. (2011). Proposta de um protocolo para o processamento de requisitos do cliente em empreendimentos habitacionais de interesse social. *Ambiente Construído*, 11, 21–37.

Miron, L.I., Formoso, C.T., (2010). Value generation in social housing projects: a case study on the City Entrance Integrated Program in Porto Alegre, Brazil, in: 18th Annual Conf. of the Intern. Group for Lean Construction. Haifa, Israel, 14-16 Jul 2010: Technion, Haifa, Israel.

Miron, L.I.G., 2008. Gerenciamento dos requisitos dos clientes de empreendimentos habitacionais de interesse social : proposta para o Programa Integrado Entrada da Cidade em Porto Alegre/RS. DSc. Federal University of Rio Grande do Sul.

Miron, L.I.G., 2002. Proposta de diretrizes para o gerenciamento dos requisitos do cliente em empreendimentos da construção. MSc. Federal University of Rio Grande do Sul.

Monteiro, D.A. de B., Miron, L.I.G., Shigaki, J.S.-I., Echeveste, M.E.S. (2015). Avaliação da percepção de valor em Empreendimentos Habitacionais de Interesse Social: perspectivas de técnicos e de usuários. *Ambiente Construído*, 15, 37–54.

Orihuela, P., Orihuela, J. (2014). Needs, values and post-occupancy evaluation of housing project customers: A pragmatic view. *Procedia Engineering*, 85, 412–419.

Pasquire, C., Salvatierra-Garrido, J. (2011). Introducing the concept of first and last value to aid lean design: Learning from social housing projects in Chile. *Architectural Engineering and Design Management*, 7, 128–138.

Ruiz, J.A., Granja, A.D., Kowaltowski, D.C.C.K. (2014). Cost reallocation in social housing projects considering the desired values of end-users. *Built Environment Project and Asset Management*, 4, 352–367.

Wang, J. (2015). Revolution of Chinese architectural design at the new-type urbanization stage. *Frontiers Architectural Research*, 4, 248–250.

Windapo, A.O., Goulding, J. (2013). Value-based perspectives of stakeholders' building requirements in low cost and government subsidised housing projects in South Africa. *Construction Innovation*, 13, 424–444.

# Post Occupancy Evaluation of University Buildings in the UK

## (Case Study: The Diamond, Sheffield)

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**Abstract:** The Diamond, housing teaching and research space for the Faculty of Engineering, represents the largest ever capital investment for the University of Sheffield. Costing £81m, construction began in 2013 and the building was officially opened on 28th September 2015. The building employs a complex Building Management System to manage the internal environment. It is an example of a modern building that has been designed to take control away from occupants and use automated systems to control environmental conditions and mitigate interventions by occupants.

This relies on the Standard Effective Temperature model to assign comfort temperatures. This is based on the PMV thermal comfort model derived from extensive laboratory experiments to establish mean thermal comfort scores (Fountain et al., 1996). However, beginning with a range of field studies in the 1970s, Humphreys and McIntyre have shown that the range of temperatures that building occupants report as 'comfortable' is wider than reported in controlled laboratory conditions.

Leaman and Bordass (2001) define Post Occupancy Evaluation (POE) as a process for creating a dynamic, continuous and improving knowledge base that can be used to continuously improve a building's performance over its life time. (Bordass et al., 2001). As many design stage decisions are based on broad assumptions of how a building will perform, conducting POE provides an opportunity for gathering real information to improve and inform future projects (Zimmerman and Martin, 2001).

The aim of this research is to investigate the relationship between the use of automated systems for indoor environmental control and user satisfaction in the Diamond building, contributing towards improving building performance and the quality of the indoor environment for users. The research employs POE as a strategy for investigating the building, including a bespoke survey to gather information about user perceptions of comfort and satisfaction with the environment.

**Keywords:** Post Occupancy Evaluation, Thermal Sensation, Occupant satisfaction, Building evaluation

## Introduction

The further and higher education sector in the UK, with a wide range of building types, user occupancy patterns and research activities, provides a challenge for the energy manager to meet all the users' needs with the minimum energy consumption (CIBSE 1997). User's needs vary, and people's behaviour is considered one of the most important significant factors that effects energy consumption. Mechanical ventilation systems (HVAC), used to maintain the quality of the indoor environment, can consume up to 50% of total energy use during operation (Vargas et al. 2014)

Normally people behave in a way that makes them feel comfortable while doing their main activities (Barbu et al. 2013). However, people's thermal sensation and perception are not always the same. Comfort temperature is changeable, as people will adapt to a range of temperatures by adjusting their clothes and/or activities or the environmental conditions according to the weather. Many attempts have been made to

predict and assume the optimal indoor temperature and determine the environmental strategy that should be used in a given situation. (Nicol et al. 2002).

But, as predicting people's behaviour is a challenge, designers may prefer using automated systems to control the indoor environment (rather than giving people the opportunity to adapt to their conditions) using HVAC systems and comfort standards as the only design parameters. Often this employed the "Standard Effective Temperature" (SET) model to assign comfort set-point temperatures. SET is based on the Predicted Mean vote (PMV) thermal comfort model which is derived from extensive laboratory experiments on groups of people in which the mean responses for feeling satisfied were recorded as set points (Fountain et al. 1996).

However, there are many cases in which a building does not perform as expected, despite the ubiquity of design standards. In addition, people's responses towards these standards vary. These problems are exacerbated in a university building like the Diamond, with a wider range of space types, user occupancy patterns and activities than other non-domestic buildings. The Building Performance Evaluation (BPE) programme was recent a four-year UK study examining how well real buildings perform. The study included schools, apartments, supermarkets, offices, health centres and houses. The end results of this study indicated that buildings were using 3.6 times as much energy as they were designed to use (Connect.innovateuk.org 2017). In order to understand the reason being this gap, known as the performance gap, tools can be used to learn from past buildings in order to improve future buildings' functionality and efficiency in terms of energy performance and user satisfaction. The need to conduct POE of the Diamond is based on: a lack of evidence about: 1) the performance of the advanced systems designers use for operating university buildings, and 2) the variety of users and their different perceptions of experiencing the same space with automated environmental controls.

### **Post Occupancy Evaluation**

Building performance can be defined as the degree to which a building can meet any or all users' expectations. Many tools have been developed to evaluate building performance, guarantee occupant requirements and save energy use. One of these is Post Occupancy Evaluation (POE) (Tookaloo et al. 2015). Zimring and Reizenstein (1980) defined POE as 'examinations of the effectiveness for human users of occupied design environments' (Hadjri et al. 2009) Leaman and Bordass (2001) define POE as an implemented process for creating dynamic, continuous improving knowledge base that can be used to continuously increase the building performance over its life-time (Bordass et al. 2001).

POE is a continuous process and should not stop as long as the building is in service. The main goal of POE to meet users' needs, then help to improve current and future buildings. The POE process should also be published and accessible to everyone as it provides systematic continuous studies for occupied buildings, sharing knowledge in order to improve building's efficiency, meet users' needs, mitigate energy use as much as possible and continuously assess current design standards.

POE emerged in the 1950s as part of a trend to apply science as an investigatory tool to solve problems arising from the building industry. It started with care facilities such as hospitals and nursing homes (Preiser et al. 2006). It has been marginalised for a period of time until it started to be taken more seriously with many clients more interested in improving the performance of their facilities and meeting occupants' needs and satisfaction (Leaman et al. 1999). During the development of POE methods, the study and evaluation of

educational environments in academic institutes has always played a main role. Since the 1960s universities have been at the forefront of POE development partnering with design practitioners (Tookaloo et al. 2015), but, there is currently no agreed strategy for POE of HE buildings in the UK, and the most up to date available guidance was published by the Higher Education Funding Council for England in 2006 (Barlex 2006).

### **Research Methodology**

100 students were surveyed to understand occupants' feelings and their satisfaction for the indoor thermal and lighting conditions inside the Diamond. The survey was conducted in June – July 2017, in different types of study spaces, including open spaces and silent rooms of various sizes. All survey responses were recorded with the corresponding date, temperature, humidity, lighting levels and clothing conditions of the participants. The survey recorded users' thermal sensation votes (AMV), thermal preference votes and the background environmental parameters for the calculation of the Predicted Mean Vote (PMV).

According to Barlex (2006), POE may be conducted with three different levels of benefits (Barlex 2006); the short-term benefit for this study is to investigate user satisfaction with the interior environment. The medium-term benefit is to develop a POE plan for the University of Sheffield. The longer-term benefit is to spread the word about the importance of performing POE in higher education buildings, and the greatest benefits will be achieved when the information is made available to everyone who can make a good use of it.

### **Post-Occupancy Survey**

The survey was divided into four main parts. The first part collected general information about the participant, his/her age, country of origin, the period of stay in the building and clothing conditions. The second part was about thermal sensation and preference, in which the participants were asked to rate their thermal sensation on the ASHRAE seven-point scale. This was to gather the quantified thermal sensation of the participants, which is known as Actual Mean Vote (AMV), which is compared with the Predicated Mean Vote (PMV) calculated from the CBE Thermal Comfort Tool, to assess the extent to which the building is meeting peoples' needs. The third part was about lighting conditions. It included two questions, the first about current lighting levels, all the on-the-spot measurements were taken during the daylight. The second question is about how much control people prefer to have over the lighting. The last part of the survey included readings of temperature, lighting intensity and indoor and outdoor humidity. All the indoor readings were measured simultaneously while people completed the survey. Spaces were divided into two groups; open and closed spaces.

### **Introducing the Case Study**

As a 24/7 facility, the Diamond (Figure 1) consists of six levels, hosting students and staff from across the university. The building hosts a range of lecture theatres, seminar rooms, open plan study spaces, library, IT services, spaces for informal study and a café at the ground floor. In closed spaces the building employs a mechanical ventilation system, however, in the main atrium, it employs a natural ventilation system. The building depends on both natural and artificial lighting. Each of the building zones has a presence detector. If no movement is registered for a specific amount of time, the system will turn off the main lights, and in return will turn it on if it detects movement.





Figure 1 The Diamond exterior (East facade) and interior view (Main Atrium)

Source: <http://www.twelvearchitects.com/portfolio/item/the-university-of-sheffield/> (accessed: 5th, July, 2017)

The building was designed by Twelve Architects, and won many awards, including the 'Design through Innovation' award in the 2016 Yorkshire and Humber Region Royal Institute of Chartered Surveyors (RICS) awards, and was also shortlisted for the Yorkshire awards from the Royal Institute of British Architects (RIBA). The building was designed as a 'smart' building, with automated control of energy management. The central atrium is naturally ventilated.

### ***Technical information***

#### ***The Ventilation system***

The building operates in a mixed mode. It has two different ventilation systems; in its closed spaces it uses a mechanical ventilation system. However, in the main atrium, it uses natural ventilation systems; the openable automated glazed louvers at the top of the interior atrium, east and west façade are automated to provide the building with natural ventilation and extract smoke. They are controlled by indoor and outdoor conditions and will not open during high winds and rains. Typical but adjustable set points for operation are; the outside air temperature has to be between 17 and 25°C. The indoor space temperature in the atrium should reach 24°C to begin opening.

#### ***Lighting***

The building depends on natural and artificial lighting. Most of the study spaces have a desk lamp overhead, which can be turned on, off, or dimmed by the user. This supplements the background lighting. Each of the building zones has a presence detector. If no movement is registered for a specific amount of time, the system will turn off the main lights and in return will turn it on if it detects movement. Lighting of corridors cannot be controlled by the end users but building managers have manual control over it. In other places, especially closed bookable silent rooms, users can control the light by turning it on or off. Projection units located at a higher level project lights toward ceiling mirrors which in return provide artificial light to all different levels in the atrium and a large room on the second level.

### **Survey Outcome**

One hundred occupants were surveyed over several days, including 55 females and 45 male students. Mostly subjects wore medium clothing (53 persons) followed by 44 persons wearing light clothing and only three people wearing heavy clothing. The Clo. values were estimated by the researcher according to observation. Suggested values for clothing conditions from the ASHRAE standard are 1.0 and 0.5 Clo, representing typical winter and



summer clothing, however no evidence is given that these are typical values. Estimating clothing values is therefore one of the key uncertainties that researchers face calculating PMV (Nicol et al. 2011).

### ***Thermal comfort***

The measurements show that the minimum temperature inside the building during the period of the research was 20 °C at the open space at the ground floor, and the maximum temperature was 25°C, with a mean temperature of 23.1°C. At the same time the lowest temperature outside the building was 15°C, and the highest temperature was 28°C, with a mean temperature of 21.1°C. After applying all the values of temperature, clothing conditions, metabolic rates, humidity and air speed using the CBE thermal tool and the preference votes from the users, Figure 2 represents the AMV on the ASHRAE Thermal Sensation Scale in relation to the PMV.

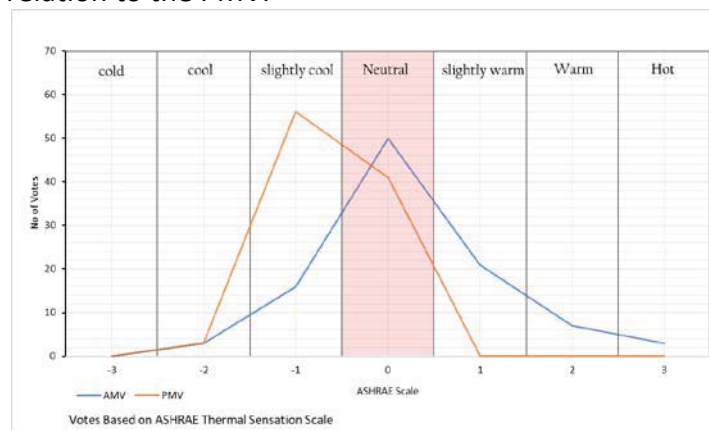


Figure 2 AMV and PMV compared  
Source: Researcher

According to the AMV, around 50% of the participants feel neutral, with 19% feeling slightly cool and cool, and 31% feeling slightly warm, warm and hot. However, the PMV suggested that 56% of people may feel slightly cool and 42% may feel neutral. This shows that the range of comfortable temperatures is wider than suggested by the PMV model, supporting similar findings as demonstrated by Humphreys and McIntyre (Leaman et al. 1999). One of the reasons that may explain the discrepancies between AMV and PMV could be the phenomenon revealed by previous studies that in naturally ventilated buildings, comfort is found to extend beyond the temperatures predicted by the PMV model. Half of the interviewed occupants were sitting in the open space, which is naturally ventilated, and standards like ASHRAE 55 were originally introduced with an assumption that centralised HVAC technology would be employed (Fountain et al. 1996). This finding implies that building users may demonstrate some forgiveness for temperatures outside of the comfort range implied by the PMV model, as the AMV demonstrates that most of the occupants are feeling neutral, and are thermally satisfied.

Figure 3 also shows the preference votes for the environment plotted over the AMV and PMV. It shows that the numbers of people who preferred no change or to feel slightly cooler are slightly greater than the numbers who were satisfied (no change) and slightly cool according to the AMV. However, the numbers of people who preferred to feel slightly warmer and warmer are slightly less than the AMV. This might be explained by occupants' expectations of the season, as occupants may prefer to feel cooler inside the building during the summer.

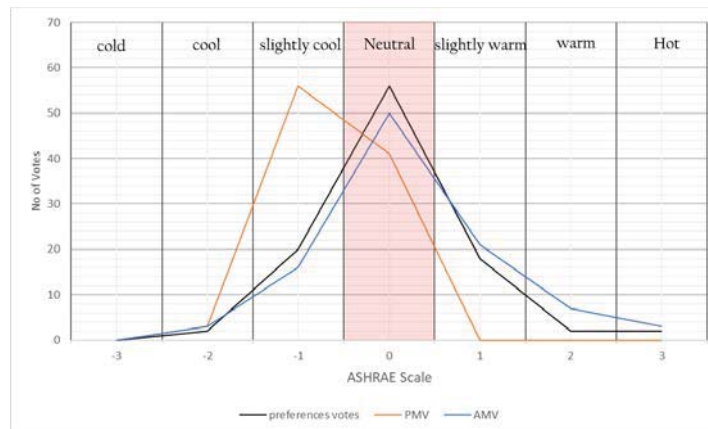


Figure 3 AMV, PMV and preferences votes plotted overlapped

Source: Researcher

However, there is broad agreement among researchers that individual control of local thermal environments is by far the best solution from a comfort and satisfaction standpoint (Fountain et al. 1996). The survey shows that 41 subjects are satisfied with the automated control system, whereas 43 subjects stated that they want a bit more control. On the other hand, there are people who do not express any desire to have more control over the environment (Figure 4).

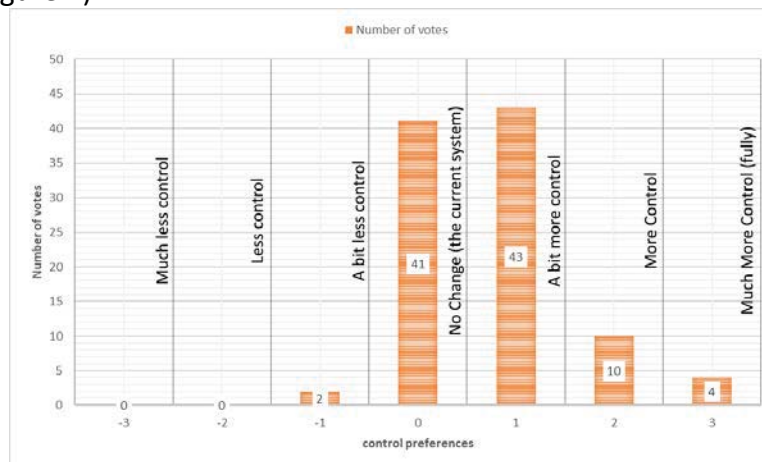


Figure 4 preferences over controlling the environment

Source: Researcher

### Lighting conditions

Figure 5 represents people's responses and the mean corresponding lighting levels for each preference. 48 users had a neutral response to the lighting when the mean level was about 500 lux, meeting the European standard for Indoor lighting (BS EN 12464-1); 29 users wanted it to be slightly lighter when the mean level was 450 lux; and 11 users wanted it to be lighter when the mean level was 400 lux. Four people wanted the light to be much lighter when the mean level was 321 lux. However, it was noticed that seven people preferred it to be slightly darker and one person wanted it to be much darker when the lighting levels were 346 and 315 respectively.

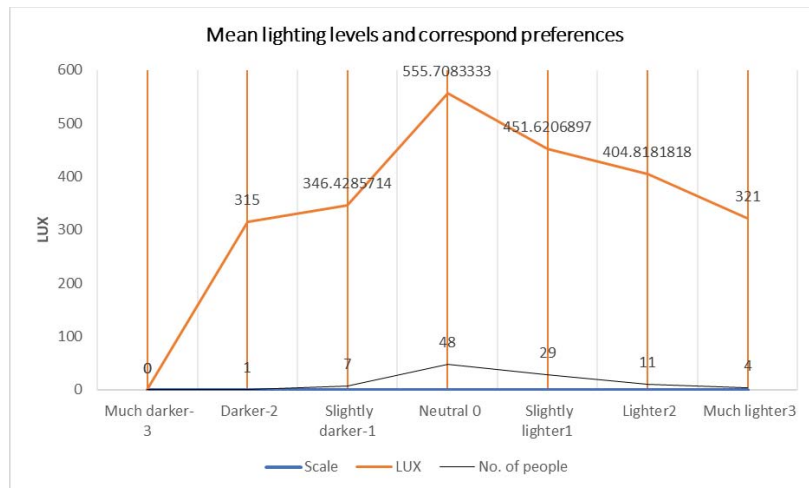


Figure 5 Preferences votes for the current lighting conditions

Source: researcher

Most people were already using laptops and PCs which do not require much light in the background. However, students pointed out the problem of glare caused by suspended lights in the open spaces and light reflectors, especially when these were facing people sitting at higher levels. Reflections were another issue mentioned by students and observed in different places around the building.

Regarding people's preferences in controlling the lighting conditions, 42% of people stated that they were satisfied, 38% of people wanted to have a bit more control and 15% wanted to have more control. Only 5 people reported that they want to have full control of the lighting conditions. However, the questionnaire did not enquire what kind of control was desired (such as turning on, off, dimming or even changing colour, which could be considered in future research).

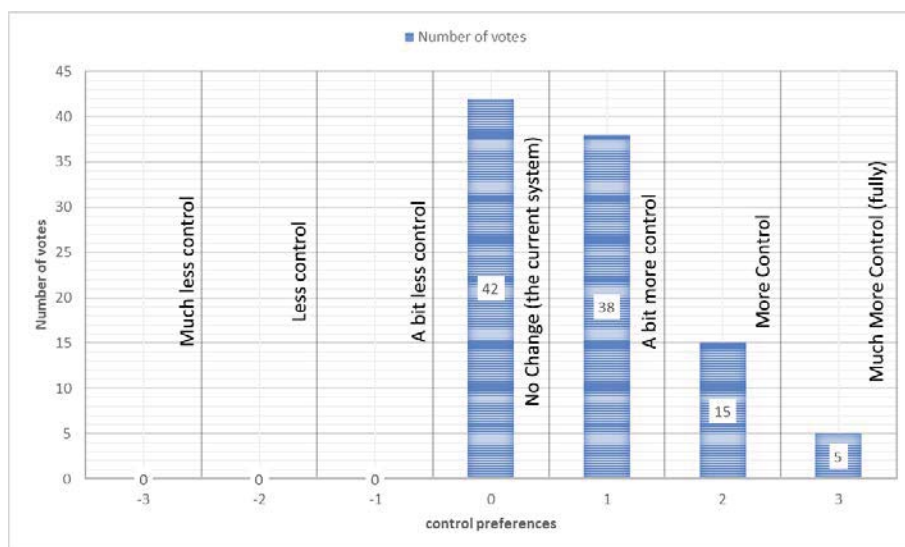


Figure 6 preferences over controlling the light

Source: researcher

### Energy consumption

Figure 7 represents the amount of energy used for the heating demand. The heating energy consumption for the Diamond in 2015 was 153.28 kWh/m<sup>2</sup>. This is 5% below CIBSE-Part F standards for typical practice (a figure of 161 kWh/m<sup>2</sup> for a naturally ventilated library). The highest consumption is in winter from December until March.

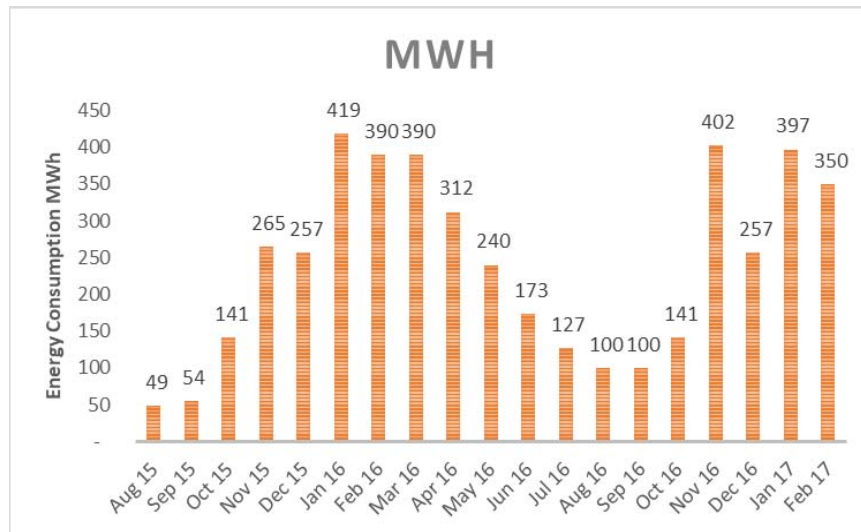


Figure 7 Monthly Energy Consumption for heating  
Source: adapted from University Facility Management

Figure 9 compares the energy consumption of the Diamond with two other university buildings in Sheffield and the CIBSE standard. These two buildings are the Arts Tower, and the Information Commons (Figure 8), Sheffield's largest library. The three buildings are different in terms of design and ventilation strategy, but are similar in terms of use patterns, with students using all three buildings throughout the day/academic year to carry out desktop study (Lawrence et al. 2016).

While this is not a full representative sample it offers anecdotal evidence that the Arts Tower, as a building with more opportunities for users to control the indoor environment, is using less heating energy than the Diamond. The Arts Tower is using more heating energy than the Information Commons, but it provides users with an easy way to control their environment by opening the windows.

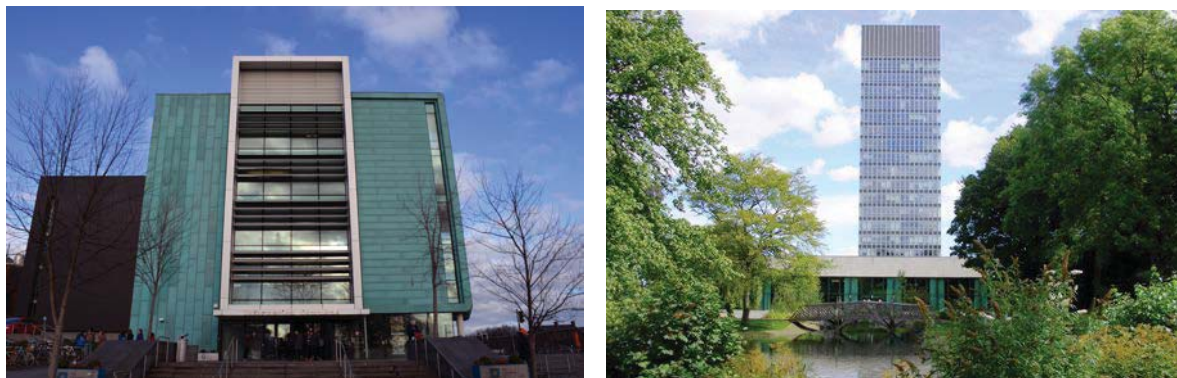


Figure 8 Information Commons to the left, The Arts Tower to the right  
Source: To the right: [https://www.sheffield.ac.uk/polopoly\\_fs/1.248578!/image/ATforCMSsmall.jpg](https://www.sheffield.ac.uk/polopoly_fs/1.248578!/image/ATforCMSsmall.jpg)

In terms of electricity consumption, the Diamond as the highest tech building appears to use less energy than the Information Commons. The consumption values for the Diamond are from December 2015 to December 2016, and have not been corrected for average degree-days. The Arts Tower as a traditional building with low technology uses less energy than the Diamond and the Information Commons.

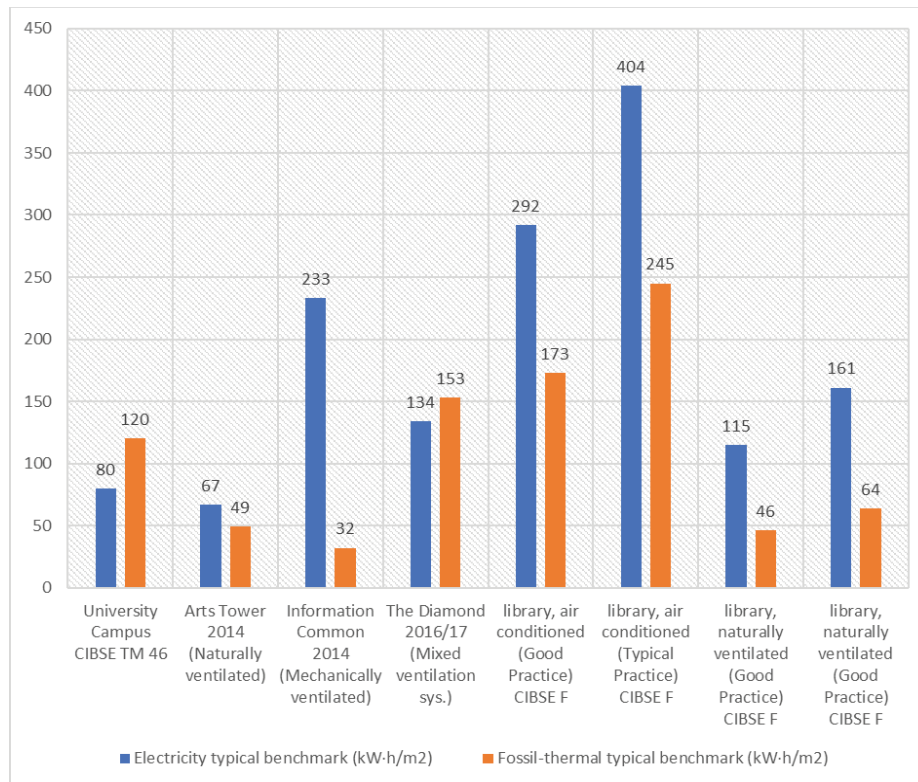


Figure 9 Energy consumption comparison

Source: Information adapted from CIBSE guide F, University State Department and (Lawrence et al. 2016)

## Conclusions and Further Research

### *In terms of thermal satisfaction*

The research was based on the hypothesis that “Mechanical solutions give a superior outcome, and people’s perception of control over their environment affects their comfort and satisfaction”(Leaman et al. 1999). However, 50% of the sample felt neutral without having control over the environment, and 41% were satisfied with the current automated system. Nevertheless, it is not a definitive proof or disproof of the hypothesis. Providing personal control in large interior open spaces usually costs more money and is often not the most efficient way of ensuring adaptability (Myerson et al. 2010). In addition, not everyone will accept the conditions resulting from individual interventions, as it was clear from individual users’ responses for the environmental preferences and feelings.

The outcome of this research shows that occupants have a level of forgiveness even if they cannot control the environment, so long as they are satisfied with the interior conditions. Further research should analyse in depth the energy use of the Diamond, as it is critical to know exactly how much energy the building is using to achieve comfortable conditions for different end uses (heating, cooling, ventilation, lighting). While the results show that the users are mostly satisfied, POE is a continuous process, so the results in this research should not be taken as final, and should be considered as a one step in the POE process.

### *In terms of lighting*

Despite 48% of the people feeling neutral, the other half of the sample desired more light, and this can be justified by the measurement readings represented in Figure 5. Most of the lighting levels at spaces located near the envelope meet the European standard for indoor



lighting (BS EN 12464-1). Meanwhile, all values below the standard were measured in the core of the building and away from the outer envelope. It was also noticed that the artificial light is turned on all of the time on most days in the inner spaces, Figure 10. This could reflect an issue with the design in terms of achieving the required levels of natural lighting, but, as there was a lack of information about the standard and sensors used in the building, further investigation is required.

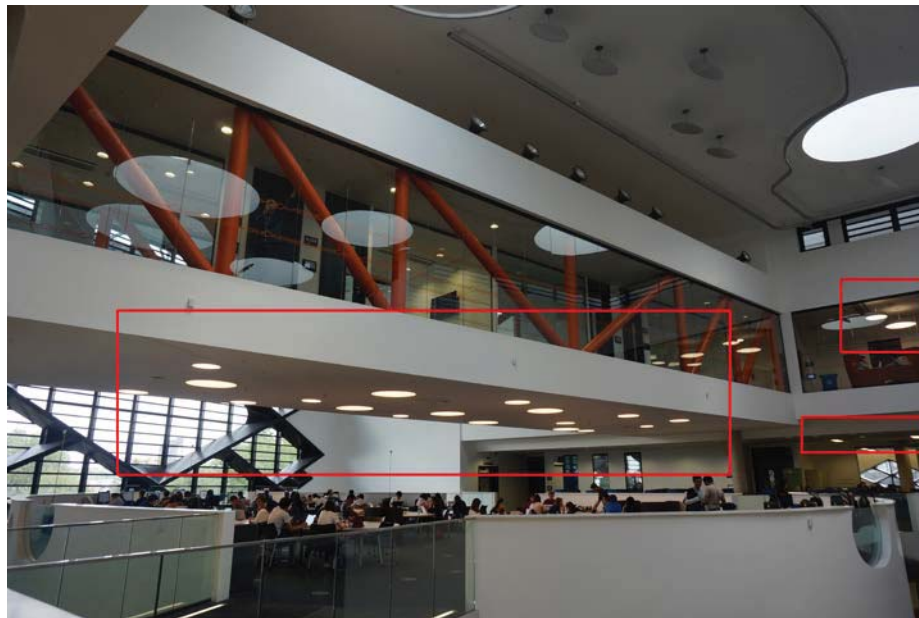


Figure 10 Artificial light turned on in the morning  
Source: Researcher

The researcher noticed the majority of users are not familiar with all the lighting control options. For instance, most of the lighting units have a dimming option, but users did not know about this feature, so it is recommended that these options should be made clearer for the user. People who were using laptops mentioned that sometimes glare from lighting reflecting on their screen was annoying, and they cannot control the light as it is operated by automated sensors. People who were studying around the outer envelope found it annoying not to be able to blind the direct sunlight if it is hitting their face or computer screens.

The researcher also observed that as users become familiar with the automated lighting they assume that the manual controlled desk lighting (fitted to all study desks) is also automated, so they leave without turning it off, causing higher energy consumption. It was also noticed that the lighting for each space is centrally controlled, so all of the lights in a space could be turned on without full occupation of the space.





Figure 11 All the lights are turned on in the library at morning without the full capacity  
Source: Researcher

### ***In terms of energy consumption***

Energy consumption readings should be considered in more detail, but this research indicates that the use of auto-controlled systems in combination with natural ventilation can be a good solution for providing thermal comfort as well as saving energy in university buildings, characterised by a wide range of space types, user occupancy patterns and activities. The research also demonstrates the importance of performing POE for university buildings to understand alternative servicing strategies and examples of good practice, and then to employ these precedents to improve the performance of current and future buildings.

### ***Further Research***

Previous surveys indicate that only 3% of British-based architectural practices regularly undertake POE on housing projects, only 9% of chartered practices offer POE to clients, and none generate revenues from POE services (Hay et al. 2017). This research has highlighted the need for people who are working in the construction sector to think again about considering and undertaking POE for current and future buildings in general, and education building in particular.

This study only focused on students' thermal comfort and lighting satisfaction for the indoor environment at the Diamond. Future research for the Diamond may consider other attributes like the design of the building itself, acoustic problems, colours, furniture, internal and external views, and could also consider different study spaces such as research laboratories, cafeterias and lecture theatres.

The difference between the Diamond and other university buildings is that, the Diamond is a 24/7 facility. It hosts varies activities including lectures, seminars, and presentations. This kind of university building is growing in popularity in order to attract students through the improved range and quality of facilities provided, and so it is important that researchers develop a thorough understanding of the unique challenges that they present. Involving the staff in the survey would be beneficial as they are working on the building regularly, doing their job within the same space. They experience the building during the full year and often over more than one year. Thus, their feedback may include comments about issues that students are not aware of, such as local problems and maintenance issues.

## References

- Barbu, A.-D., Griffiths, N., et al., (2013). Achieving energy efficiency through behaviour change: what does it take. *European Environment Agency (EEA), Copenhagen*.
- Barlex, M., (2006). *Guide to post-occupancy evaluation*. [Place of publication not identified]: Melvyn Barlex.
- Bordass, B., Leaman, A., et al., (2001). Assessing building performance in use 5: conclusions and implications. *Building Research & Information*. **29. (2)**, 144-157.
- Cibse, E. (1997). ENERGY CONSUMPTION GUIDE 54. *Energy efficiency in further and higher education—cost-effective low energy buildings* CIBSE.
- Connect.Innovateuk.Org. (2017). Building Performance Evaluation - innovateuk [Online]. [19/08]. Available from: <https://connect.innovateuk.org/web/building-performance-evaluation/about-bpe>.
- Fountain, M., Brager, G., et al., (1996). Expectations of indoor climate control. *Energy and buildings*. **24. (3)**, 179.
- Hadjri, K. & Crozier, C., (2009). Post - occupancy evaluation: purpose, benefits and barriers. *Facilities*. **27. (1/2)**, 21-33.
- Hay, R., Samuel, F., et al., (2017). Post-occupancy evaluation in architecture: experiences and perspectives from UK practice. *Building Research & Information*. 1-13.
- Lawrence, R. & Keime, C., (2016). Bridging the gap between energy and comfort: Post-occupancy evaluation of two higher-education buildings in Sheffield. *Energy and Buildings*. **130**. 651-666.
- Leaman, A. & Bordass, B., (1999). Productivity in buildings: the 'killer' variables. *Building Research & Information*. **27. (1)**, 4-19.
- Myerson, J., Bichard, J.-A., et al., (2010). New demographics, new workspace : office design for the changing workforce [Online]. /z-wcorg/. Available from: <http://public.eblib.com/choice/publicfullrecord.aspx?p=539830>.
- Nicol, J. F. & Humphreys, M. A., (2002). Adaptive thermal comfort and sustainable thermal standards for buildings. *Energy and Buildings*. **34. (6)**, 563-572.
- Nicol, J. F. & Wilson, M., (2011). A critique of European Standard EN 15251: strengths, weaknesses and lessons for future standards. *Building Research & Information*. **39. (2)**, 183-193.
- Preisner, W. & Vischer, J., (2006). *Assessing Building Performance*. Taylor & Francis.
- Tookaloo, A. & Smith, R., (2015). Post Occupancy Evaluation in Higher Education. *Procedia Engineering*. **118**. 515-521.
- Vargas, G. A. & Stevenson, F., (2014). Thermal Memory and Transition in Lobby Spaces. *Energy Procedia*. **62**. 502-511.

# What are the social benefits of energy efficient retrofit of social housing?

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## Abstract:

Current understanding of effective climate change mitigation acknowledges the requirement for a socio-technical approach that addresses environmental, economic and social issues. With the prediction that the cumulative cost of social inequality related issues, between now and 2050, may be more than double that of the impact of climate change in the UK, and that the most economically vulnerable will be the most negatively impacted by climate change, the paper investigates whether these issues can be addressed simultaneously. The research investigates the social benefits of a social housing energy efficiency retrofit programme. It focuses on the case study of a 1960's inner city council estate that underwent an energy efficiency refurbishment. The study explores the effectiveness of the retrofit in reducing gas and electricity consumption, CO<sub>2</sub> emissions and the impact of the retrofit on the residents.

The retrofit was assessed using empirical data that measured CO<sub>2</sub> emissions pre and post refurbishment, energy use in apartments, interviews with residents, the council and comparative research literature.

The evaluation of the findings confirms some reduction in gas consumption and CO<sub>2</sub> emissions.

The research finds the socio-economic impact on the residents includes confidence in maintaining an affordable warm home, increase in disposable income and wellbeing. The retrofit provides long-term security of resident's homes and community pride.

The negative impact included additional use of electric heating and cooling due to inadequate retrofit. This creates doubt about the efficacy of energy savings. The occupiers commented on "construction fatigue".

The paper concludes that there is potential to address aspects of social inequality and climate change through informed energy efficient retrofit. Critical to its success is stakeholder engagement at all levels and stages supported by clear communication on energy saving benefits. To achieve this, multi-disciplinary input, funding, support and education led by the UK and local governments is required.

**Keywords:** Social housing, benefits, energy efficiency, retrofit

## Introduction:

Currently the 27 million UK dwellings contribute 20% of UK CO<sub>2</sub> emissions (CCC 2017). 75-85% of these existing dwellings will be in use in 2050. The majority of these have poor thermal performance and emit unnecessary amounts of CO<sub>2</sub> (Shorrocks 2005). Reports commissioned by Committee on Climate Change (CCC 2017) and others indicate that little progress has been made in improving the energy efficiency of existing housing stock. This report, amongst others, confirms that to be effective in reducing energy use and CO<sub>2</sub> emissions in housing, a retrofit programme requires a focus on socio-economic as well as energy issues. This can offer opportunities for sustainable development that positively impact environmental, social and economic aspects of society and address the problems of inequality. As New Economics Foundation (Coote 2017) and others confirm *"there is evidence that more equal societies are better able to achieve carbon reduction and avoid depletion of natural resources"*

Research by LSE into the effects of the government Decent Homes programme found that the 'whole building' approach improved not only energy efficiency and CO<sub>2</sub> emission reductions it also increased residents' well-being and the value of the neglected estates (Power 2008). It is this vital link between energy efficiency and social benefits that is explored in this paper, based on thesis research carried out in 2013. Building from prior research, a questionnaire was used with residents of the case study estate in Islington, along with empirical data on temperature from dwellings on the estate to explore the effect of the

retrofit programme on occupants.

Identifying the success, weakness and impact of an existing programme informs an understanding of the drivers and barriers to improving energy efficiency. It also identifies the social issues that could be managed more effectively to reduce negative social impact. The results of the research provide recommendations for future retrofit programmes to deliver effective energy savings and address social inequality.

**Social Sustainability:** The UK is witnessing further government cuts on welfare and an increase in social inequality (JRF 2015, NEF 2017, NEF 2009a). Research on social sustainability and its critical role in 'sustainable development' emphasises that social issues have to be addressed effectively for future survival (Bruntland 1987). NEF (NEF 2009a) presents a scenario for tackling climate change and economic inequality. By illustrating the impact of social inequality as a fiscal sum the necessity for including it in climate change debate is evident. NEF estimate that the cumulative cost associated with climate change in the UK is £1.6-2.6 trillion between now and 2050 (ibid). In comparison, the cumulative cost of dealing with social problems associated with economic inequality could be £4.5 trillion. These costs include NEETs (Not in Employment or Educational Training), health, crime, substance misuse, mental health and spatial inequality (ibid). The research is backed by studies such as 'The Spirit Level' (Wilkinson, R and Pickett, K 2009), 'The cost of exclusion' (Prince's Trust, McNally, S and LSE study 2010) and (Holmes, C 2003) and Joseph Rowntree Foundation research (Hastings 2015) that detail the consequences of rising social inequality and its cost to society.

The Marmot Report (Marmot M, 2011) highlights the link between inadequate housing and the issues above. It provides evidence on the negative health impacts of cold homes and fuel poverty including direct impacts such as increased excess winter deaths, higher incidence of ill health and indirect impacts such as negative influence on children's educational attainment and development that later bears on their employability and income potential. In an article in Public Health Today, a member of the Marmot Review Team recommended the improvement of domestic energy efficiency as a means to address both fuel poverty and climate change (Allen, J. 2011).

**Energy efficiency studies:** Studies on the effectiveness of UK energy efficient retrofit measures on existing buildings including Kirklees Warm Zone (Webber 2015), TSB (2012), UCL Energy Institute (2012) United House (2011) and BRE Case Studies (2010) were reviewed. The majority of these provide detailed information on the fabric improvements and data on the thermal performance of the alterations, improved U-values, embedded carbon, carbon emissions and energy consumption. Lowe (2007) argues that a 60-70% reduction in CO<sub>2</sub> emissions from existing housing can be achieved through a combination of retrofit and decarbonisation of the energy supply. German retrofit programmes have achieved 80-88% reduction of CO<sub>2</sub> emissions since 2005 by applying Passivhaus standards and providing 'clean' energy (Kuckshinrichs, W. 2010). In comparison, DBEIS (2016) data confirms CO<sub>2</sub> emissions from UK buildings are 15% lower than in 1990. The obstacles to achieving this in the UK are explored by Dowson et al (2012) who state that energy saving should focus on insulation of buildings. This is reiterated by Ravetz (2008), observing that despite post-retrofit improvements on SAP rates and housing standards, CO<sub>2</sub> emissions from housing is increasing due to lack of insulation and an increase in use of electrical appliances. This is supported by reports from DBEIS (2016) and CCC (2017).

What is often missing from the investigations, except in the studies High Rise Hope (Power 2012) and Hong, S et al (2009), is the qualitative analysis of the social impact of the work on

the residents, particularly in areas of deprivation where residents are more vulnerable to climate change (JRF 2011). Power (2012) is unusual in adopting social science and building physics methodology to record the energy efficient retrofit of a social housing estate in west London and links these findings to residents' socio-economic development.

**Background to Bunhill Ward and King Square Estate:** The case study, King Square estate, London EC1V is located in Bunhill Ward, Islington. Islington has the 14th highest deprivation score in England (Islington 2011). The following quote from Islington Council summarises core issues in the area:

*"Bunhill ward scores well for income, employment and crime levels in the borough and poorly for health, housing, education and training. The specific zone of King Square Estate is in overall index of multiple deprivation national score between 10 and 20% most deprived"* (Islington 2014b)

The ward's housing stock is 58% council housing, 82% of this are purpose built flats. The most common income band is £15-20,000. 13% of the population claim out of work benefits, 8% are long term unemployed and 28% of households meet ONS deprivation conditions (Islington 2014b).

The estate was built between 1959-65. It is the highest density high-rise housing estate in Islington. It consists of two highrise and six lower buildings constructed from precast concrete units. Five of these are included in the study; Barnabas, President, Rahere, Telfer and Turnpike.

In 2005 under the HCA CESP, Islington initiated a carbon management plan to reduce CO<sub>2</sub> emissions of its building stock. The estate retrofit was enabled by Islington Council's Decent Homes funding. There were no regulations or standards on energy saving retrofit clarified, mandatory targets or how to achieve these. The retrofit contract included limited cavity wall and roof insulation, new Upvc double glazed windows. Most of the concrete cladding was not insulated. The BMS was upgraded by installing communal boilers with external temperature monitors to regulate heat demand and individual thermostats were added to radiators. However, no central control for regulating the heating in the flats was fitted (Islington Council 2013).

The literature review revealed that despite existing studies on energy saving retrofit and the social impact of cold homes, there is little that links empirical findings with social studies. This paper addresses the gap in research through a 'multi-strategy' research method establishing a relationship between the quantitative and social research to enable comparative evaluation of results. The objective is to bring awareness to the potential of effective energy efficiency in mitigating social inequality and Climate Change.

### **Methodology:**

How does one measure the social benefits of a retrofit programme? The study is based on a multi-strategy research proposal to investigate the subject. It requires empirical data and qualitative information for complimentary research as described by Bryman (2005). The empirical data investigates the ability of the programme to improve the energy efficiency of the estate. This information supports the inquiry into the residents' perception of the effects of the retrofit programme. The quantitative data is based on Islington Council gas consumption and CO<sub>2</sub> emission records for the estate and temperature recordings over a period of time of various properties. The qualitative data is based on semi-structured interviews with residents. They come together in the analysis concurrently.

Research analysis shows that depending on computer models to predict results in lieu



of monitoring the actual performance of the post completion building performance, can provide inaccurate results. Bordass and Leaman's (2009) post occupancy studies identified that in most cases the actual energy performance of buildings is worse than the predicted model. This is supported by Hong et al (2009) study of the Warm Front programme that concluded that due to the differences between modeled and monitored data it is critical to gain post- occupancy empirical data to assess the actual effectiveness of energy efficiency work.

Studies highlight the importance of quantifying internal dwelling temperature in comparison to external temperature fluctuations to ascertain how successful the retrofit work has been in moderating internal temperature fluctuations caused by external conditions (Hong, S et al, 2006, Dowson, M et al 2012). The evaluation of whether the internal temperature is maintained through increased heating or fabric efficiency is clarified when comparing this to gas consumption rates. By contrasting temperature fluctuations in individual flats and linking these findings to external temperature data and pre/post-retrofit gas consumption the efficiency of the programme can be monitored.

**Empirical data collection:** Original data from temperature monitors located in various flats and gas consumption records provided by Islington Council were analysed. These records provide monthly gas consumption figures for each of the four buildings monitored pre and post-retrofit. The internal temperature data is recorded by installing two temperature loggers in different rooms. Another monitor logs the temperature of the flow and return pipes in each flat. Monitors located near the estate record the external temperatures during the monitoring period. This method was adopted as an appropriate and unobtrusive means of gathering information.

**Qualitative data:** Analysis included detailed reports of resident thermal comfort levels and behavior patterns. The investigation model is based on interviews with residents responding to a questionnaire. The focus of the questions was to explore the residents' perspective of retrofit and associated aspects of social sustainability to further understanding of the impact of the programmes. A semi-structured questionnaire includes closed questions to elicit specific information and open questions enabling respondents to discuss their experience not specifically included in the questionnaire. These answers can be loosely categorised as positive or negative impact. Their value is to provide personal anecdotes describing a situation not contained in closed questions. The results' analysis acknowledges that the findings do not portray a preconceived view of the impact of retrofit on residents. They are for comparison with the empirical data findings and to record personal accounts of issues investigated.

### **Results and findings:**

The investigation of findings of the empirical research including gas consumption records pre and post retrofit and temperature records of individual flats provides information on how the buildings perform, especially during cold spells.

### **Empirical findings:**

To retain anonymity, the estate buildings are referred to as Buildings A, B, C, X, Y. Figures 1 and 2 show results of gas consumption pre and post retrofit for Buildings X and Y. Table 1 shows weather normalized gas consumption figures pre and post retrofit linked to energy and CO<sub>2</sub> emissions savings of the buildings. Buildings A, B and Y are grouped as they are served by the same boiler. Note that A & B retrofit includes limited wall insulation whilst building X had full cavity wall insulation and Y had no insulation. The impact of this can be



seen in the resulting post retrofit energy and emissions reductions.

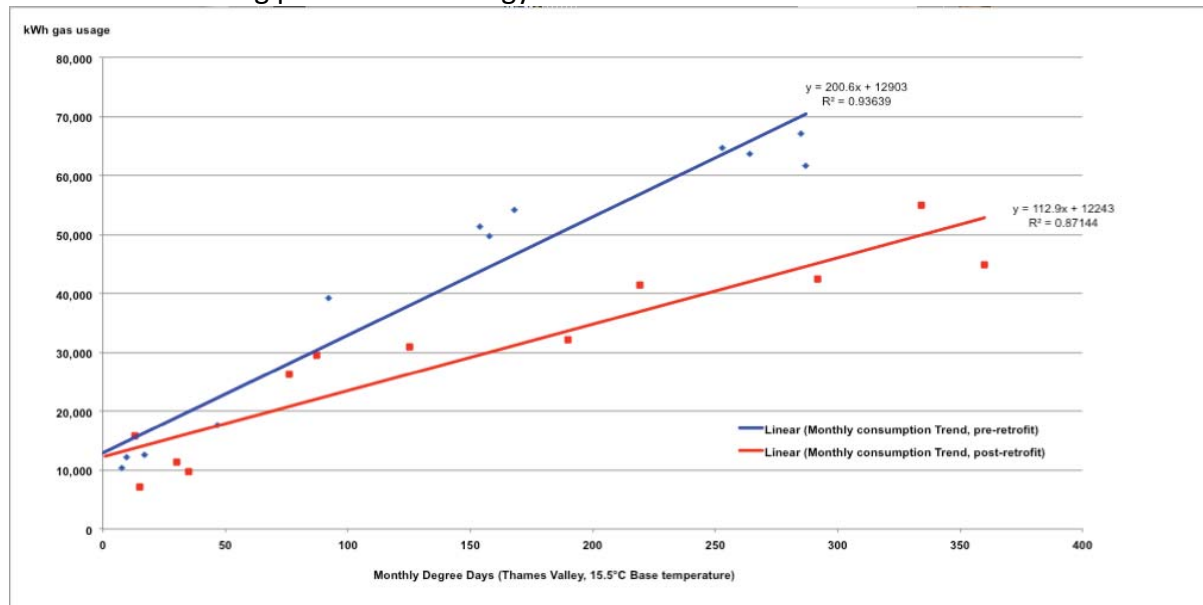


Figure 1. Graph showing pre (blue 2002-03) and post-retrofit (red 2008-09) monthly gas consumption trend for Building X (Islington Council Energy Team records 2013).

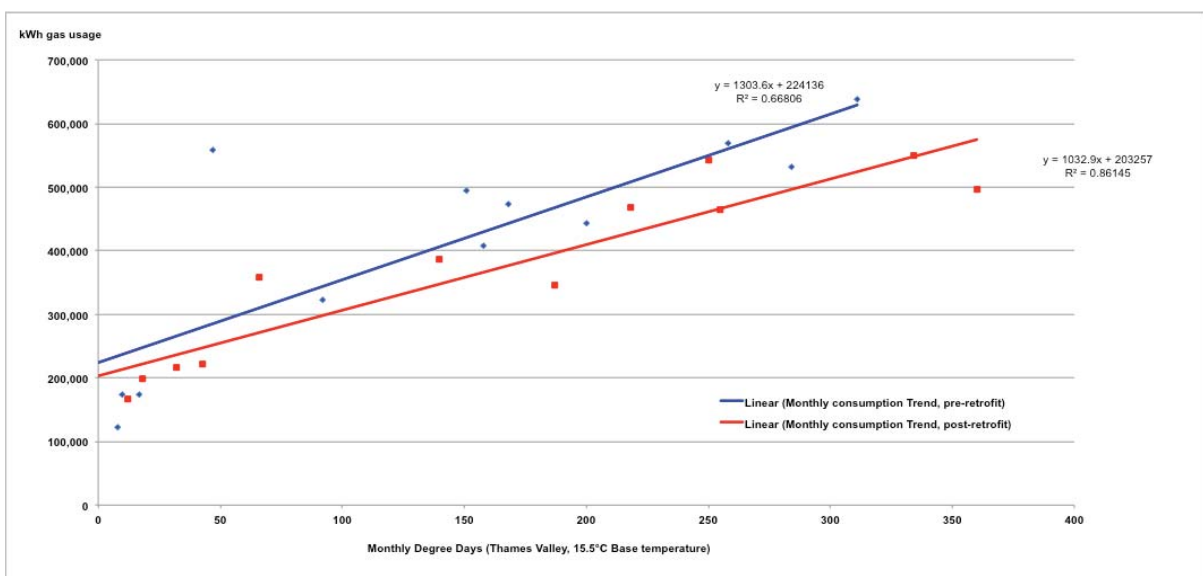


Figure 2. Graph showing pre (blue 2002-03) and post-retrofit (red 2008-09) monthly gas consumption trend for Building Y (Islington Council Energy Team records 2013).

Table 1. Results for Buildings A,B,Y and X

	Building X data	Buildings A,B & Y data
Dwellings boiler serves	16	A,94 B,36 Y,97 total 227
Retrofit measure	Double glazing, roof and cavity wall insulation, BMS improvements	Double glazing, roof and part cavity wall insulation of A & B, minimal insulation of Y. BMS improvements
Weather normalized* total gas consumption pre retrofit (kWh)	514,111	5,017,862
Weather normalized* total gas consumption post retrofit (kWh)	349,120	4,283,862

Energy saved (kWh)	164,991	734,018
% saved	32.1	14.6
tCO <sub>2</sub> emissions saved	31.3	139.5
Annual tCO <sub>2</sub> emissions saved/dwelling	1.96	0.61

### **Discussion of results:**

Several factors influence gas consumption including external temperature, building fabric, exposed external area, boiler settings, distribution system and resident behavior. The effect of the weather can be gauged accurately (the colder it gets, the more heating is required and the more gas is consumed), less so for the other matters. To account for the influence of external temperature, the table shows 'weather corrected' data; ie: consumption data adjusted to reflect number of days the temperature fell below 15.5 °C. The percentage of energy and CO<sub>2</sub> saved across the estate after retrofit reflects the quality and extent of installation work, mainly whether cavity wall insulation was included. Building X (results in fig.1 and table 1 above) showed energy savings of 15% above Building Y. The difference in approach was that Building X had cavity wall insulation and Building Y did not. These results are similar to Energy Savings Trust (EST 2007) findings.

The data recorded by monitors logging internal room, flow and return temperatures of flats over a three-month period revealed resident thermal comfort patterns. The mean temperature of the bedrooms at 22.2-23.9°C is 4-5°C higher than average UK standard bedroom temperature at 18°C. The mean living room temperatures of 20.6-23.6°C are 0-3°C higher than average UK standard living room temperature at 21°C. Heating is on for 18 hours per day October - May. The residents of poor/un-insulated flats confirm they cool fast when not heated and are often cold during the coldest months and too hot during the summer despite the Trend boiler having weather compensation controls.

The recorded data informs the relationship between external and internal temperature fluctuation and gas consumption, the effect of external temperature on boiler performance and the association between poor building fabric, poor boiler function and high energy demand as confirmed in other studies on energy efficiency; High Rise Hope, BRE studies, EST studies, Hong et al, Bushell (op.cit). It confirms that whilst double-glazed windows and improved BMS reduce energy consumption and carbon emissions, they alone are not effective enough to achieve required national CO<sub>2</sub> emission reduction targets. Without regulatory standards and targets for retrofit, energy saving methods and results are confused and disappointing.

The internal temperatures confirm the effect of occupant behavior on actual energy savings and stress the need to address this when implementing energy saving programmes. Other research identified the consequence of 'Rebound effect' (Hong et al 2009, Sorell 2007, Barker et al 2007) and the importance of including thermal adaptation opportunities in evaluating post energy efficiency programme data (Baker 1996). This is supported by studies into adaptive behavior including Nicol and Humphries (2002) and Bordass and Leaman (2009) who reiterate that buildings without thermal adaptation opportunities perform less well than buildings with, even with an efficiently performing fabric.

**Questionnaire results:** The semi-structured questionnaire providing qualitative data explores the residents' perception of the effects of the retrofit programme. The findings include thermal comfort, energy bills and associated benefits. Twenty-three questionnaires

were completed representing 5% of the total estate households. Of the households interviewed, half are at home part time and a third are at home full time.

*Energy efficiency works:* The majority of respondents commented on the improved thermal comfort provided by the double-glazed windows. Some were less satisfied due to poor specification and installation. Most respondents from blocks that had cavity wall insulation were not aware of it. A few commented on the improved boilers and heating system and ongoing problems with heat supply during cold weather. Most residents felt that despite the dirt, noise and disruption, the work had been worth doing.

*Thermal comfort and adaptation:* The majority of respondents confirmed that their flat is warmer after the retrofit work mostly due to the double-glazed windows.

Table 2. Respondent replies to whether the flat is warm when it is cold outside.

Is your flat warm when it is cold outside?				
Type of dwelling	Cavity wall insulation dwellings; Buildings A & B		No wall insulation; Buildings Y & C	
Is your flat warm when it is cold outside?	Yes	No	Yes	No
Total	5	1	6	11
% of total number of households	4%	0.8%	3%	4.5%

Table 2 shows that in cold weather, the majority of residents in the insulated buildings are warm and those in the un-insulated buildings are not. Many in the un-insulated flats commented that maintaining warmth depends on the heating being on for eighteen hours a day. However, as the monitoring of internal temperatures exposed, the expectations of thermal comfort are high. When the flats are cold, 25% residents use electric heaters, extra clothing and blankets to stay warm. When their flats are too hot, most residents open windows and doors (rather than reduce the thermostats) and use electric fans (20%) on hot days to reduce temperatures. These findings expose the limitations of the retrofit programme and significant requirement of energy consumption in summer and winter to compensate for its inadequacy.

Table 3. Annual energy bills per flat type from questionnaire answers for A,B,C, X and Y

Flat type	Mean annual bill	Lowest annual bill	Highest annual bill
1 bed middle	884.79	564.00	1213.32
2 bed corner	1038.52	821.64	1316.64
2 bed middle	1259.21	917.64	1824.00
3 bed corner	1715.52	..	.

*Energy bills:* Residents were asked how much they spend on electricity, how this has changed recently and if they find energy prices reasonable. Essential to healthy housing conditions is the capacity to keep warm. The data in table 3 suggests that there is a disparity in residents' ability to do this and that energy bills vary considerably in similar flat types. Energy distribution across the estate varies and some residents receive communal heating & hot water, others do not. The lowest bills are for flats that receive communal heating and hot water. The difference in energy use for these depends on occupant number and behaviour. When asked if energy costs are reasonable, those who benefit from communal heating & hot water said they were, others noted that electricity costs were high and they felt they had little choice but to pay.

*Social benefits of retrofit:* Residents were asked questions aimed at establishing the quality of their life with respect to their homes, the estate and the effects of the retrofit. Respondents were asked what they liked and what were the worst aspects of their home. The majority of people said they liked their home; many connected their home experience to their experience of the estate and ongoing construction. The positive views confirm the benefits of the retrofit programme such as the windows, which enhance thermal performance and contribute to energy and cost savings. Respondents emphasized the importance of seeing that the council invests in the estate. It increases a sense of pride and security in their home, surroundings and community and many confirm they feel safer. The NEF dynamic model of well-being states that it depends on successfully addressing "*physical and psychological needs...income, housing, education, connectedness, health..*" (2017b). Therefore, increasing energy performance of the buildings and subsequent reductions in outgoings can directly contribute to social benefits with improved housing quality, associated improved health, education, security and income.

A resident of Building Y confirmed;

*"Yes I like the flat. It's cosy and feels safe with 24hr concierge. It is bright, sunny and clean Great that the heat cost is included in rent. Worst is water heater cost & damp in bathroom."*

The negative comments largely reflect management issues, the reality of recent tenancy policy and overcrowded flats. The common complaint about noisy neighbours is exacerbated by the un-insulated concrete structure that contributes to the cold interior. The repercussions of this include increased energy bills, fuel poverty and poor health (Harker, L 2006, Marmot 2011).

When residents were asked their views on the estate the overwhelming majority said they were happy there. The primary positive factor is the strong community, which is central to well-being. Residents appreciate the public areas that provide a social space for residents. These findings are supported by NEF research (2009b) on well-being that identifies "creating opportunities for social connection" and "be active" in its principles of establishing well-being. The awareness of investment in the estate to provide these facilities alongside energy efficient homes reinforces a sense of well-being in the respondents. This is supported by the increased social benefit the retrofit programme offers with warmer homes and subsequent improved living conditions, health, education, security and more disposable income.

Long-term residents added;

*"Good neighbourhood feel, very friendly and safe." "I love my life here!"*

The “construction fatigue” partly due to the retrofit work, exacerbates distrust in the prospect of more energy efficiency programmes, particularly when residents doubt their efficacy. The main causes for concern, which undermine the positive aspects, tend to be social; management issues and public spending cuts. Overall the respondents were satisfied with their quality of life on the estate, 43% added that it was improved and 23% felt that their health had improved after retrofit. Most did not feel this was directly linked to the retrofit work though several acknowledged that the warmer flat (new, less drafty windows) had improved their quality of life.

The results demonstrate that the social benefits associated with the retrofit work fall into several categories, immediate, medium and long term. The immediate benefits include the improved thermal performance of the windows and BMS that offer a “cosy flat”, the security of being able to afford this and lower heating costs. The economic savings will benefit the more vulnerable residents. In the medium term, improvements include a positive impact on health, education and subsequent employment prospects of residents that benefits society. In the long term, the energy and CO<sub>2</sub> emission savings will benefit everyone.

**Conclusion:** The findings indicate that some improvements in energy saving and residents’ socio-economic situation can be achieved through retrofit. The extent of its efficacy depends on various factors. As confirmed in the empirical study, an insufficient programme limits the potential improvements of the work. This results in low energy, costs and CO<sub>2</sub> savings, residents continuing to use additional energy and confusion over the usefulness of the programme. The results of the empirical study establish that retrofit has reduced gas consumption and CO<sub>2</sub> emissions at King Square estate, with greater savings for the insulated building. Internal temperatures in the less exposed, insulated flats are more stable than those in flats with little/no insulation in more exposed locations. The questionnaire investigation reveals that most respondents felt the flats were warmer after the retrofit. They felt increased security knowing they could afford to be warm in winter. The tenants’ gas bills have reduced recently (partly due to the effect of retrofit). Respondents value council investment in the estate through retrofit and it increases a sense of pride and long-term security in the community.

The investigation also exposes the insufficiency of the work. Actual post-retrofit saving of energy and CO<sub>2</sub> is of average UK standard and poor in comparison to Swedish (Power 2008) and German (Kuckshinrichs, W. 2010) examples. Energy bills reveal that many occupants spend large sums on electrical energy. Despite high internal temperatures and extended periods of heating, significant numbers of occupants need electric heating and additional clothing to keep warm. Communication issues and varied construction quality has caused concern over additional refurbishment and distrust in the efficacy of the retrofit programme.

Research into the subject provides further evidence for wider ranging social benefits associated with energy efficient retrofit. The warmer dwelling is associated with the improvement of health, educational attainment and employability of the community. The reduction of energy bills diminishes occupants’ outgoings and fuel poverty. The increase in value of the estate strengthens the community against the negative aspects of regeneration. The construction process could benefit the community through skills training, apprenticeships and effective communication on energy saving and behavior. The findings emphasise the importance of both top down and bottom up support for retrofit. Without fully engaging with residents or receiving government financial and technical support, UK

retrofit programmes will continue to underachieve. The absence of specific government led targets, clear technical information or funding has created misgivings and poorly realised intentions. Lack of monitoring of completed projects exacerbates this as problems are not investigated, little improves and the positive findings are not communicated.

The social benefits of retrofit are significant, quantifiable and achievable. To realise these, future retrofit programmes need intelligent management, informed funding and expert delivery.

The recommendations can be summarised as:

- Clear Government legislation and standards for retrofit; key to identifying the quality and extent of investment required
- Skills and technical training at all levels for informed design, specification and delivery
- Improve monitoring of projects to establish efficacy of measures and impact on residents
- Communication from authorities with clear messages about the benefits
- Improve resident involvement and understanding on how their behavior influences the outcome of the programme
- Revise funding strategy

The value of this study is that it identifies the environmental and social potential of what can be achieved through effective retrofit and its contribution to addressing social inequality. It exposes the UK barriers to achieving these benefits and where consideration is required to overcome them. Addressing the issues of climate change and inequality is urgent and the proposal made by NEF (2009) to simultaneously tackle these appears possible through effective retrofit. It requires multi-disciplinary input, funding, support and education. Without these, as witnessed at King Square Estate, the potential benefits are limited.

## REFERENCES

- Allen, J (2011): Shocking annual death toll from cold homes is preventable. Public Health Today. Sept 2011 p7. Available at [www.fph.org.uk](http://www.fph.org.uk) (accessed 12.04.2013)
- Baker, N. (1996): The Irritable occupant: recent developments in thermal comfort theory. Arq: Vol 2: Issue 2. Dec 1996, pp. 84-90
- Barker, T., Ekins, P. & Foxon, T., (2007): The macro-economic rebound effect and the UK economy. Energy Policy, 35(10), 4935-4946.
- Bordass, B. & Leaman, A. (2009): Design intent to reality: Using post occupancy evaluation for better design and operation. Available at: <http://www.usablebuildings.co.uk/> (Accessed 27.03.2013)
- BRE Building4Change (2010): Internal insulation of Linden Lea and Wenlock Edge, Dorking, Surrey. Available at: <http://www.building4change.com/page.jsp?id=1345>. (Accessed 12.04.2013)
- BRE Building4Change (2013): Industry leaders call for cross-party policies after just four households take up Green Deal improvements. Available at: <http://www.building4change.com/page.jsp?id=1874> (accessed 04.07.13)
- Bruntland G (1987): Our Common Future. Report of the World Commission on Environment and Development. United Nations.
- Bryman, A. Teevan, J (2005): Social Research Methods, Ontario: Oxford University Press Canada 2005.
- Bushell, E (2009): What can Local Authorities do to reduce CO2 emissions from housing?. Thesis for The Graduate School of the Environment, Center for Alternative Technology, Machynlleth, Powys, UK.
- Camden/Islington Public Health (2015): Index of Multiple Deprivation Report
- Committee on Climate Change (CCC) (June 2013): Meeting Carbon Budgets: 2013 progress report to Parliament. Available at <http://www.theccc.org.uk/publication/2013-progress-report/> (accessed 28.06.13)



Committee on Climate Change (CCC) (June 2017): 2017 Report to Parliament – Meeting Carbon Budgets: Closing the policy gap. Available at <https://www.theccc.org.uk/wp-content/uploads/2017/06/Closing-the-UKs-climate-change-policy-gap.pdf>

Davis, A., Hill, K., Hirsch, D. and Padley, M. (2016), *A Minimum Income Standard for the UK in 2016*, Joseph Rowntree Foundation. Retrieved from <https://www.jrf.org.uk/report/minimum-income-standard-uk-2016>

DBEIS 2016 Updated Energy & Emissions Projections. Available at

<https://www.gov.uk/government/publications/updated-energy-and-emissions-projections-2016>

Dowson, M. Poole, A. Harrison, D. Susman, G (2012): Domestic UK retrofit challenge: Barriers, incentives and current performance leading into the Green Deal. *Energy Policy* 50: 294-305

Energy Savings Trust, (2007): Energy efficient refurbishment of existing housing, Energy Savings Trust. Available at: <http://www.energysavingtrust.org.uk/business/Global-Data/Publications/Energy-efficient-refurbishment-of-existing-housing-CE83-GPG155>.

Harker, I (2006) *Chance of a lifetime: The impact of bad housing on children's lives*. London: Shelter

Holmes, C (2003): *Housing, Equality and choice*. IPPR, London

Hong, S., Gilbertson, J., Oreszczyn, T et al (2009): A field study of thermal comfort in low-income dwellings in England before and after energy efficient refurbishment. *Building and Environment*. 44: 1228-1236

Hong, S., Oreszczyn, T., Ridley, I. (2006). The impact of energy efficient refurbishment on the space heating and fuel consumption in English dwellings. *Energy and Buildings* 38: 1171–1181.

Islington Council Energy Services Team (2013): *Bunhill Heat and Power: An area based approach*. Talk given at Green Sky Thinking. 16.04.13.

<http://www.islington.gov.uk/services/housing/counciltenantsandleaseholders/your-tenancy/tenancy-services/heating/communal-heating/Pages/communalheatingcharges2010-11and2011-12.aspx>

Islington Council (2011a). *Islington's Core Strategy*. Available at [www.islington.gov.uk](http://www.islington.gov.uk) (accessed 24.09.2012)

Islington Council (2014). *Bunhill Ward Profile 2014*. Available at [www.islington.gov.uk](http://www.islington.gov.uk) (accessed 11.11.17) [https://evidencehub.islington.gov.uk/PublicRecords/Public-health/Quality-and-performance/Profiles/2016-2017/\(2016-06-15\)-Ward-Profile-Bunhill-2014.pdf](https://evidencehub.islington.gov.uk/PublicRecords/Public-health/Quality-and-performance/Profiles/2016-2017/(2016-06-15)-Ward-Profile-Bunhill-2014.pdf)

Joseph Rowntree Foundation (2015): *The cost of the cuts: the impact on local government and poorer communities*. Hastings, A., Bailey, N., Bramley, G., Gannon, M., Watkins, D.

Joseph Rowntree Foundation (2011): *What are the social impacts of climate change in the UK?* Available at: <http://www.jrf.org.uk/media-center/climate-change-injustice> (accessed 05.10.12)

Kuckshinrichs, W., Kronenberg, T., Hansen P (2010): The social return on investment in the energy efficiency of buildings in Germany. *Energy Policy* 38: 4317-4329

Lowe, R (2007): Technical options and strategies for decarbonizing UK housing, *Building Research & Information*, 35:4, 412-425

Marmot M (2011): *The health impacts of cold homes and fuel poverty*. Pub Friends of the Earth, May 2011, London

Marmot, M (2011): *Fair Society, Healthy Lives* in proceedings of the CARDI International Conference 2011, Dublin, Ireland Available at [www.marmotreview.org](http://www.marmotreview.org) (accessed 12.04.2013)

NEF (2017a) *Building a new social commons*. 2<sup>nd</sup> May 2017. Coote, A. Accessed at <http://neweconomics.org/2017/05/building-new-social-commons/>

NEF (2009a) *The Great Transition: A tale of how it turned out right*. 19th October 2009. S Spratt, A Simms, E Neitzert, J Ryan-Collins (accessed 09.04.2013)

NEF (2009b): *"National accounts of Well-being: Bringing real wealth onto the balance sheet"* London 2009. P48.

NEF (2017b) *'Inequality is tearing us apart'*. Quick, A. Available at

<http://neweconomics.org/2017/01/inequality-is-tearing-us-apart-and-its-all-of-our-responsibility-to-fix-it/>

Nicol, J.F., Humphreys, M.A.: Adaptive Thermal comfort and sustainable thermal standards for buildings. *Energy and Buildings*. Vol 34, Issue 6, July 2002, pp 563-572.

Power, A. (2008): Does demolition or refurbishment of old and inefficient homes help to increase our environmental, social and economic viability? *Energy Policy* 36: 4487–4501.

Power, A., Bates, K., Lane, L (2012): High Rise Hope: The social implications of energy efficiency retrofit in large multi-storey tower blocks. *LSE Housing and Communities*. October 2012. Case Report 75.

Prince's Trust, Mc Nally, S and S, Telhaj, S: *The Cost of Exclusion: Counting the cost of youth disadvantage in the UK*. London. Center for Economic Performance, LSE. Prince's Trust publications, London 2010

- Ravetz, J., (2008): State of the stock—what do we know about existing buildings and their future prospects? *Energy Policy* 36, 4462–4470.
- Shorrocks, L., Henderson, J., Utley, J., 2005. *Reducing Carbon Emissions from the UK Housing Stock*. BRE Press, Watford, UK.
- Sorrell, S., 2007. *The Rebound Effect Report*, UK Energy Research Centre. Available at: <http://www.ukerc.ac.uk/ResearchProgrammes/TechnologyandPolicyAssessment/ReboundEffect.aspx> [Accessed 15.05.13].
- Technology Strategy Board Publications. Case Studies. Low Carbon retrofit creates cosy home. Available at: <http://www.innovate.org/content/casestudy/low-carbon-retrofit-creates-cosy-home.ashx> (accessed 15.04.2013)
- Technology Strategy Board Publications. Case Studies. Low Carbon life for terraced houses. Available at: <http://www.innovateuk.org/content/case-study/low-carbon-life-for-terraced-houses.ashx> (accessed 15.04.2013)
- Technology Strategy Board/Oxford Council (2013): Oxford Whole House Carbon Reduction project. Available at: <https://docs.google.com/viewer?a=v&pid=gmail&attid=0.1&thid=13dcbd17e602324f&mt=application/pdf&url=https://mail.google.com/mail/u/0/?ui%3D2%26ik%3De85797a98f%26view%3Datt%26th%3D13dcbd17e602324f%26attid%3D0.1%26disp%3Dsafe%26zw&sig=AHIEtbSggsGkqMPw8sTbQpofITOGgPAlSA> (accessed 03.04.2013)
- UCL Energy Institute (2012): Energy use in the UK building Stock: new empirically based models. Available at: <http://www.bartlett.ucl.ac.uk/energy/research/themes/buildings/energy-use-in-the-uk-building-stock> (accessed 15.04.13)
- United House. (2011) Colne and Mersea Low-Carbon Refurbishment Project. Available at: [www.unitedhouse.net/projects](http://www.unitedhouse.net/projects): (accessed 12.04.2013)
- Utley, J., Shorrocks, L.D., 2008. *Domestic Energy Factfile 2008*, Building Research Establishment. BRE Press, Watford, UK.
- Webber, P., Gouldson, A. Kerr, N (2015): The impacts of household retrofit and domestic energy efficiency schemes: A large scale, *ex post* evaluation. *Energy Policy*, vol 84, Sept 2015, p 35-43
- Wilkinson, R and Pickett, K (2009): *The Spirit Level: Why more equal societies almost always do better*. Pub. Allen Lane, Penguin Books, London, England.

# Harmonising energy use behaviour of British Asian households towards sustainable housing

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## Abstract

Recent studies show that actual energy demand from low carbon new-build homes can be up to 40% above expectations and energy savings from thermal upgrades are often under predicted. The inefficient behaviour of its occupants is identified as a contributing factor of this “performance gap”. This behaviour is also believed to be significantly correlated to the households’ socio-economic characteristics. While building simulation has made significant progress, the representation of occupants and their behaviour needs further work.

This research investigates the energy use behaviour of a specific demographic and ethnic group, the British Asian households. A large-scale housing survey is used to gather self-reported information about the British Asian households’ energy use behaviour, for instance, heating patterns, appliances use, ventilation behaviour, as well as other socio-economic characteristics. Data collected will be analysed and transformed into energy models, which includes Space heating behaviour models, electrical appliances and lighting use models, Ventilation behaviour models, and architectural archetypes that represent behaviour patterns for different demographic groups. The outcome of this research demonstrates how social perception and economic aspirations limit the acceptability of sustainable design and construction strategies.

This research involves active community participation and engagement; a major part of the dissemination will aim at communicating the research findings to the British Asian households, which will have a direct impact of energy reduction by informed behaviour choice. Further, this research will define the low carbon housing strategies and improved energy use predictions for the British Asian households.

**Keywords:** Energy behaviour, British Asian, Sustainable housing

## Introduction

The UK has committed to achieve 80% reduction in CO<sub>2</sub> emissions by 2050 against the 1990 baseline (DECC and Treasury, 2015). Among other sectors, it is critical to focus on domestic sector, as it contributes about 27% emission. Though government legislation addresses the mitigation strategies by setting stricter regulations for the new build, it is very difficult to upgrade the existing housing stock. Due to the very slow replacement cycles and long physical lifetimes, attention must also be placed upon the existing housing stock, which is expected to make up at least 70% of the UK’s total housing by 2050 (SDC, 2006). Among the factors affecting the energy consumption, Occupants behaviour plays a pivotal role. However, the lack of understanding of the households’ behaviour has led for assumptions which mostly predict higher energy saving compare to the actual saving. On the contrary, evidences point out the under prediction energy saving from thermal upgrades (Tahir and Walker, 2013).

There is a difference between the occupants’ behavior and assumptions at different stages and it is attributed as prime reason for the performance gap (de Wilde, 2014). There is considerable research to demonstrate the predicted and measured energy consumption and relate it to performance gap (Khoury et al., 2017, Menezes et al.,

2012). For instance, de Wilde (2014) in a review of the core reasons behind the performance gap and the implications thereof has identified three types of performance gap; predictions vs. measurement, machine learning vs. measurement, and prediction vs. displayed energy performance. However, there is limited research to explore the correlation of performance gap to the households' socio-economic characteristics. While building simulation has made significant progress, the representation of occupants and their behaviour needs further work.

Lack of knowledge and household behavior has been identified as main reason for the gap between the energy reduction prediction to actual savings despite of awareness of the climate change and increasingly stringent regulations (Pan and Garmston, 2012). Building users were considered as passive recipients of thermal stimuli to maintain the thermal balance reflecting the Fanger's model (Fanger, 1972). Recent studies have linked occupants' thermal experiences and expectations to the indoor conditions and to the climatic condition (Berry et al., 2014) and researchers have argued for understanding households' expectations and satisfying their desire for thermal comfort as one of the key drivers to reduce energy use (Berry et al., 2014).

In the domain of sustainable housing, both a qualitative approach and quantitative strategies are essential to the understanding of social and cultural dynamics as well as to measure and benchmark performance. Most of the process, from the beginning, including the Club of Rome, has relayed heavily on quantitative mathematical methods (Danilov-Danil'yan et al., 2009). Most of the studies evaluating performance of the energy efficient homes or refurbishment design process are quantitative and measure empirical data and most of the qualitative factors like, individual comfort variation, occupants' energy behavior is generalised (Thomas and Duffy, 2013, Konstantinou and Knaack, 2013).

Until recently, house-building targets and neighborhood planning lacked clear strategy to understand households energy behavior while developing sustainable communities (Power, 2008). Many energy efficient initiatives including net zero energy homes have been adopted as a financially viable, energy reduction models (Berry and Davidson, 2015). However, households, their expectations and its impact on energy usage are hardly considered in these models. The hierarchical approach to reduce energy consumption in buildings includes building envelop, energy efficient equipment and renewable power. However, none of these approaches acknowledge the behavior of households and its influence on operation of buildings while reducing the energy consumption (Maslesa et al., 2013).

The implication of behaviour pattern is further complicated when energy reduction run contrary to the prevailing practices or encouraged logical solutions. For instance, the average temperature maintained in the UK household is around 18<sup>0</sup> C in winter (Waters, 2017). All the energy prediction is calculated based on this fact; whereas, expatriates from the tropical countries prefer to keep their homes warm and at 21.4<sup>0</sup> C (Satish, 2017). The difference in internal temperature of the average UK households to that of British Asians is significant as every degree of higher internal temperature will increase the household energy consumption by 10 percent (Trust, 2017). British Asians, also referred as South Asians in the United Kingdom, Asian British people or Asian Britons, are persons of Asian

descent who reside in the United Kingdom (Smith, 2004) and they constitute about 5 percent of the UK population (White, 2012) and hence their behaviour pattern would have huge impact on the energy consumption.

For British Asians, though it appears to be way higher compare to UK average, it is perceived as a positive move to not bring down the temperature drastically and align themselves in reducing energy. In this context, this paper explores the behaviour pattern of the British Asian households, their socio-economic characteristics and its impact on the energy behaviour.

## **Methodology**

This research builds on the previous research and aims to test the energy use behaviour of a specific demographic and ethnic group, the British Asian households in the UK and compare with that of the Indian homeowners and a large-scale, city wide, socio-technical survey conducted as part of the EnerGAware project (Jones et al., 2016, EnerGAware, 2017). This work builds on the extensive research conducted in India, wherein the homeowners' aspirations are mapped to the energy demand the ongoing research on social housing in Plymouth on the other.

This research targets the British Asians and the questionnaire forms are delivered to British Asians. The contact list of British Asians is developed through snowball sampling or chain-referral sampling and by approaching various cultural and community organisations and societies. The survey questionnaire is carefully developed to overlap with the EnerGAware project and the field works carried out in India. A small- scale housing survey was distributed to gather self-reported information about the British Asian households' energy use behaviour, as well as other socio-economic characteristics. chosen Survey questionnaires were collected from 40 households, who are British Asians living in Plymouth, the UK. Questionnaires are collected from homeowners settled in the UK from different Asian ethnic background. While distributing the questionnaires among owner-occupiers, special care was taken to ensure that different neighborhoods were represented. This included the city central area, neighborhoods around Derriford hospital and neighbourhoods in the villages near Plymouth. The social, economic and educational background of the respondents are mapped to similar representation of respondents in India. A wide spectrum of respondent occupations was collected and special attention was paid to reflect the different age group and domicility of the households.

The outcome of the questionnaire survey triangulated with the literature studies and the surveys conducted in India on one hand and the survey outcome of the EnerGAware project on the other. More than 200 homeowners were surveyed in a South Indian city, Mysore and the same questionnaire with modification to reflect the climatic and socio-cultural conditions is used as part of this questionnaire. Similar questions to relatively similar demographic has enabled to compare the survey outcomes. On the similar lines, part of the questionnaire of the EnerGAware project is used to compare the feedback of respondents of British households and British Asian households. Respondents have reflected various energy related issues including household preferences, ventilation, energy

related habits and energy consumption. This paper focuses on two key issues, socio-economic preferences and energy behaviour, for further analysis and discussion.

## **Fieldwork Analysis and Discussion**

There is a convincing relation between the social-cultural practices and energy consumption behavior of the homeowners. Previous research has established a strong correlation between the homeowners' aspirations and its impact on sustainable housing in India (Satish and Brennan, 2015).

### **Socio-economic preferences**

Although a growing population seeks to accommodate valid aspirations to achieve higher levels of prosperity, it is still imperative to reduce carbon emissions. Whilst a low carbon society for developed nations can be defined as "inventing low carbon technology and reducing carbon dioxide emission by the middle of 20th century" (Skea and Nishioka, 2008), for developing nations, the achievement of low carbon communities must go hand in hand with achieving wider development goals. Furthermore, while acknowledging the role of technology, an emphasis has to be placed on the importance of lifestyle and social change (Skea and Nishioka, 2008). In this context two surveys conducted in different economic background, are compared to examine the socio-cultural preferences of households.

The traditional housing typology was reflective of the social and cultural values of the homeowners. In the revised model, households' aspirations and their reflections were examined by asking them about their expectations of the house in terms of appearance. When asked about 'what their house represent', Asian homeowners tend to give highest priority to the appearance of their home and more than a third of the respondents wanted their house to reflect the wealth of their family. Contrary to this, none of the British Asians responded felt that their house should reflect the wealth of their family. Similarly, more than 23 percent of the Asian homeowners want their home to reflect the status of their family. Whereas, less than 10 percent of British Asians believe it is important in the UK (Figure 1).

The distinctiveness of the new class structure has rested on a range of representational practices centred around particular characteristics of consumption, style and social distinction (Fernandes, 2000b). These have their ramification on the spatial reorganisation of neighborhoods within cities and small towns. In this reorganisation, households have developed new suburban aesthetic identities and lifestyles that seek to change the visual signs of public spaces (Fernandes, 2000b). As scholars like Fernandes have argued, expression of the economic mobility and demonstration of newfound wealth is a key dimension of the homeowners in emerging world (Fernandes, 2000a, Fernandes, 2006). Whereas, living in a relatively established residential suburbs, with known and established history of the property value, British Asians won't find it a requirement to express their wealth outside.



Migrated households tend to give importance to the social and cultural values and are conscious of the cultural background as a mechanism to develop the family cultural values and explore socio-cultural activities (Castles, 2000). Nearly third of the respondents in the UK felt that their home should reflect the cultural taste of the family and 35 percent responded wanted their home to reflect the character of the family. Contrary to this, Asians do not consider it as important to reflect the cultural taste and very few homeowners, less than 3 percent wanted their home to show the cultural taste of the family (Figure 1).

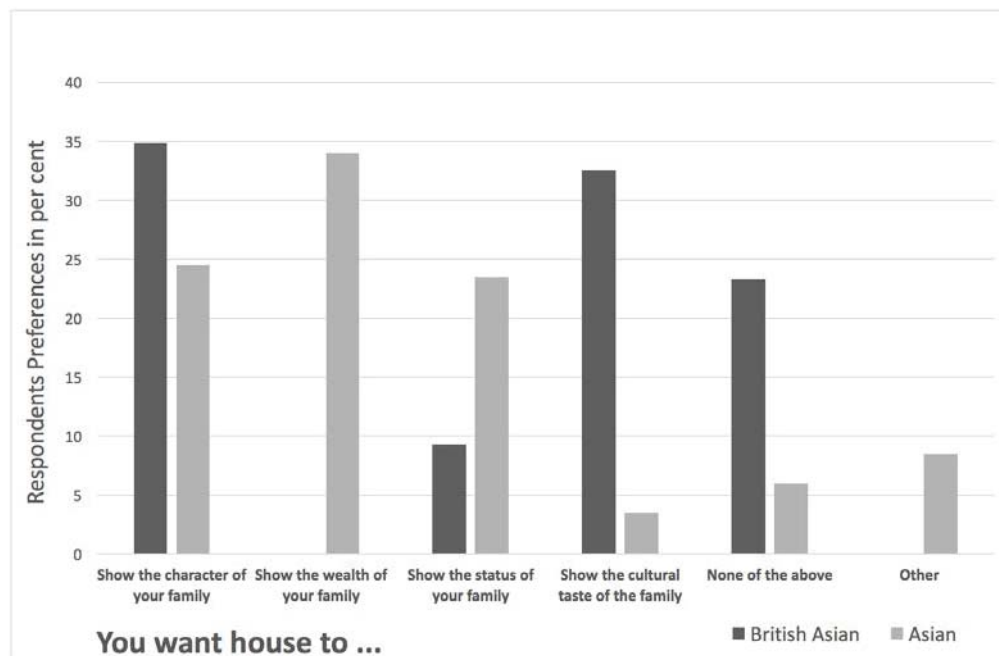


Figure 1. Respondents preferences for their home appearance.

Homeowners values would have a direct bearing on the selection process and preferences during the home construction or selection process. This is evident from the survey; wherein both Asians and British Asians have expressed nearly similar preferences when they were asked as what they would prefer to compromise in case of constraints. Although the preferences are similar in case of finishing material, furniture and area of space, they differ considerably in case of number of rooms and appearance.

In case of constraints, the British Asians give importance to area or size of the spaces they use and they are willing to compromise on number of rooms and appearance. Nearly 25 percent of the British Asians are ready to compromise on number of rooms and appearance, whereas in case of Asians, less than 10 percent would prefer to compromise on the appearance (Figure 2). Notable difference in preferences is that of equipment and appearance. More than 13 percent of the Asian homeowners are ready to compromise on equipment whereas British Asians consider this is a vital element of their house and none are ready to compromise on this (Figure 2). The reasons could well include the equipment required due to climatic conditions, like, water heater, and refrigerator.

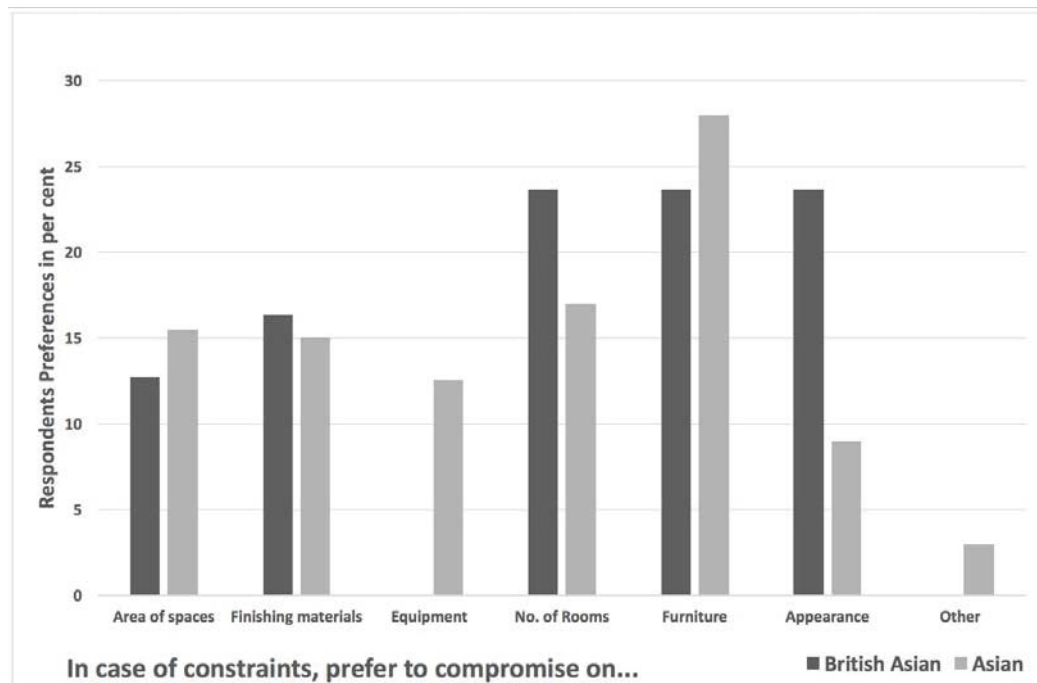


Figure 2. Respondents priorities in case of constraints.

One of the elements which reflect the cultural beliefs over the scientific or rational understanding is 'preferences for Vastu'. The original understanding of Vastu in the ancient India was developed in its entire system of building technology with the understanding of the climatology (Patra, 2009, Kannan and Jani, 2010). British Asian respondents include Asians from Pakistan, Bangladesh and Sri Lanka and in some of these places Vastu practices are not prevalent now. In spite, more than 30 percent would like to follow Vastu while selecting or building their home in the UK (Figure 3). In the context of the climate and geographical condition, understating of Vastu in the context of Indian sub-continent is not same as in the UK with limited clarity/research in this regard. The underpinning factor is that, Vastu followed as a belief in India has been carried on and adopted more in the social and cultural context in the UK. This is evident as nearly same percent of respondents likely to prefer vastu in both India and the UK, in spite of the education background of the households in the UK. This study clearly demonstrates the correlation between the beliefs and resultant value system and its impact on households' choices.

Comparative study of Asian and British Asian households' aspirations demonstrates a consistence in the preference for cultural values. This comparative study also demonstrates, how households tend to carry the cultural values and recreate them in the migrated place.

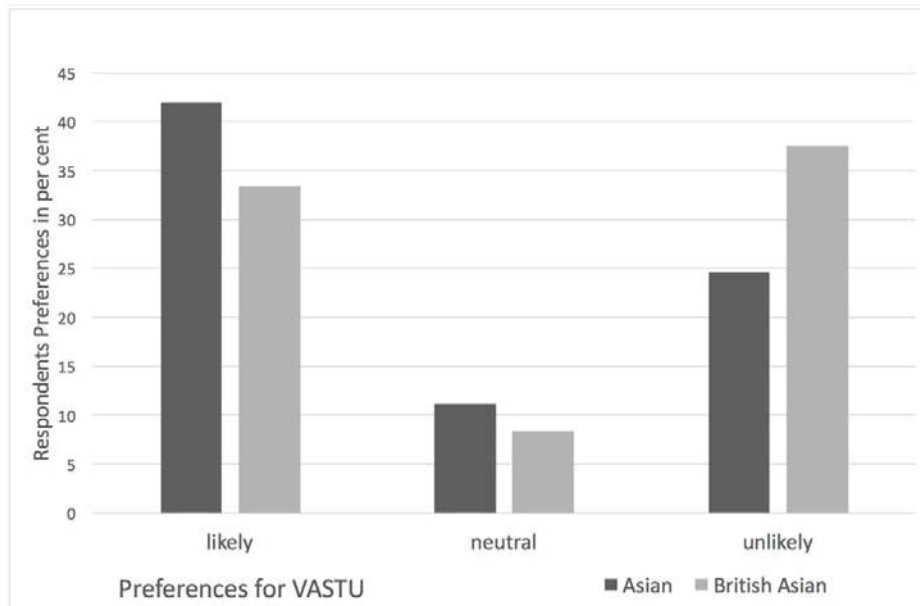


Figure 3. Respondents belief in Vastu.

#### Energy Behaviour:

One of the key difference for British Asians born and raised in Asia would be to acclimatise to the UK climate and hence understand the difference in the energy consumption in the homes. This section analyses the energy behaviour of the British Asians in Plymouth and compare with the similar survey of British (White British) household conducted by the EnerGAware project (EnerGAware, 2017).

To understand the awareness of energy consumption of the households, they were asked 'whether they understand how their home uses energy': More than 45 percent of the British households tend to or strongly agree that they don't understand the energy usage in their home. Whereas, about only 25 percent of the British Asians households expressed that they are ignorant of their energy behaviour (Figure 4). Their view is more pronounced where more than a third of British Asians understand their energy usage, whereas only 4 percent of British households strongly disagree that they don't understand their energy consumption pattern (Figure 4).

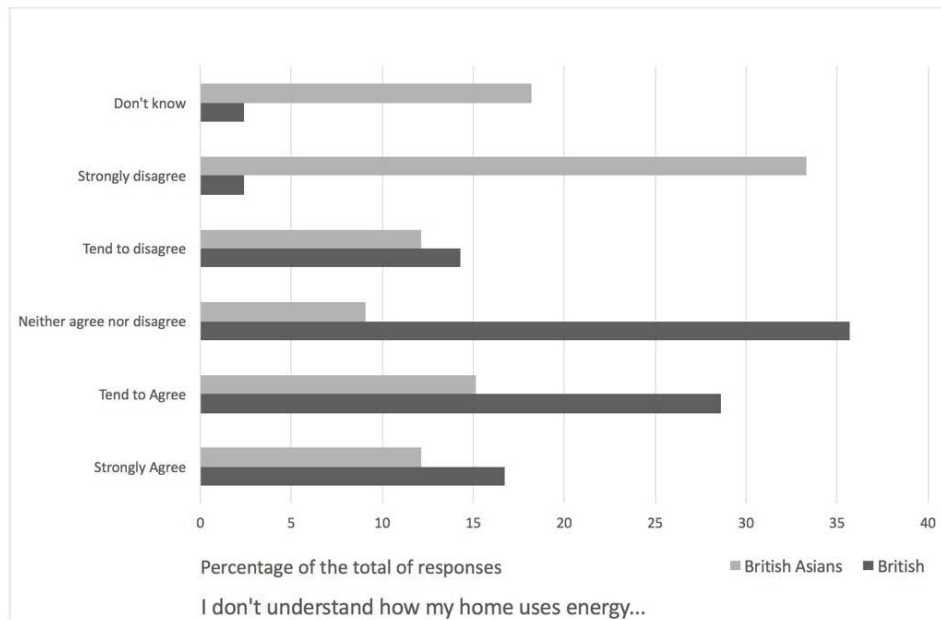


Figure 4. Respondents understanding of energy usage.

Influence of cultural and social values are evident as British Asians have a better understanding of their activities and energy use in spite of migrating from a tropical country and not lived in the similar climatic condition throughout their life, albeit second generation British Asian households.

Contrary to their differences in understanding of the energy consumption, nearly same percent of British and British Asian households expressed that they have control over how much energy consumed in their homes. Only difference is that nearly 10 percent of the British Asians are not aware their energy consumption, whereas less than 3 percent British household don't have control over the energy consumption (Figure 5). Understanding of the energy consumption and its impact on British Asians further reinforces the impact social values on households' preferences.

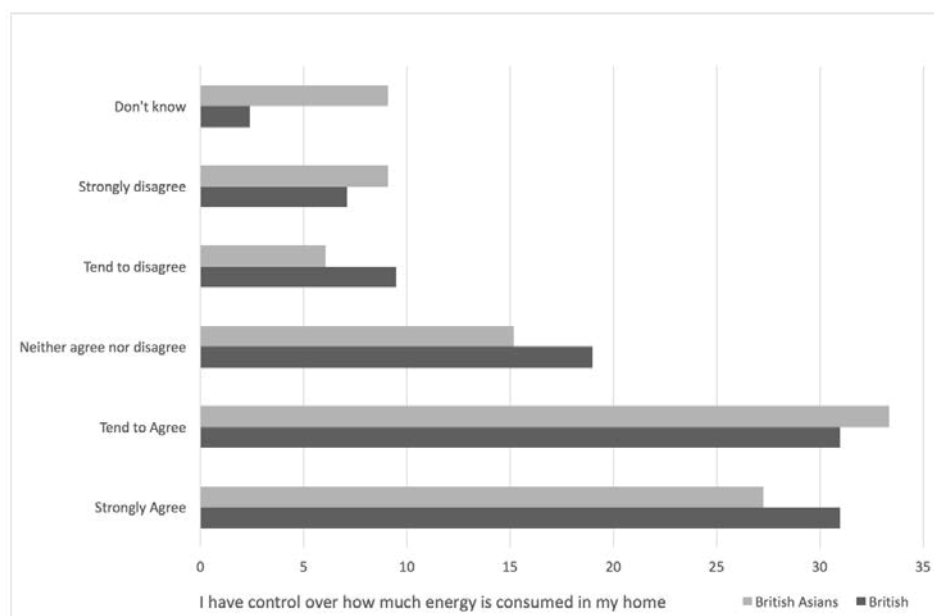


Figure 5. Respondents understanding of energy consumption.

Another aspect which connects homeowners' practices to their social and cultural background is their empathy towards sustainable world (Satish, 2013, Deepika, 2008). When asked about their intention to save energy, more than 85 percent of British Asians said that they often think about saving energy, whereas only about 75 percent British household think of saving energy (Figure 6).

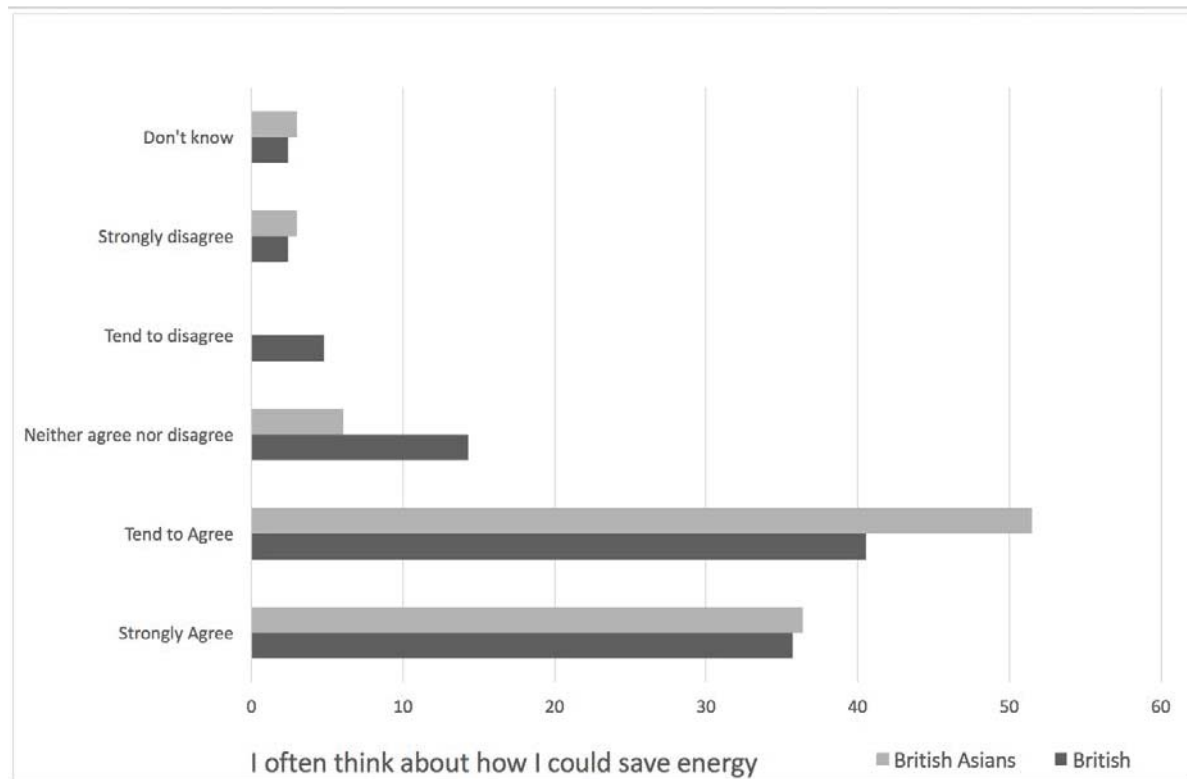


Figure 6. Respondents willingness to save energy.

Finally, both British and British Asian households believe that they will not be able to save any more energy. Lack of clarity, and uncertainty is evident in British Asians, as nearly 30 percent neither agree or disagree. lack of awareness and information are key reasons for more than 15 percent British households to say that they don't know whether they can save any more energy (Figure 7).

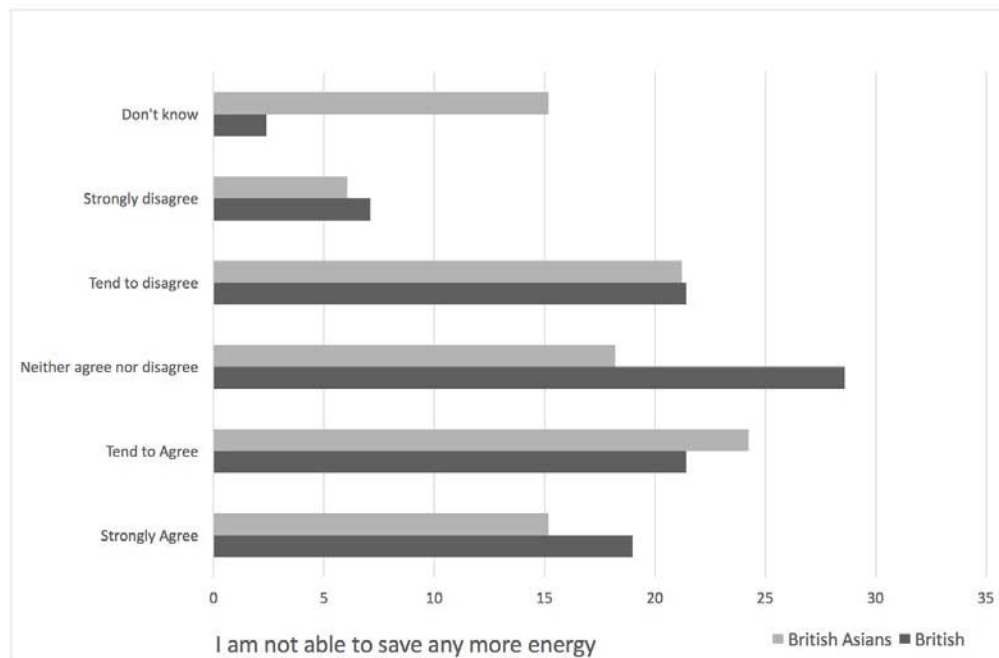


Figure 7. Respondents ability to save energy.

## Conclusion

While acknowledging the role of policy guideline, emphasis needs to be given to the importance of lifestyle and social change. This research focus on the sustainable built environment as social and cultural phenomena that can allow insights in the effective formulation of localised and relevant low carbon strategies and thus provide bottom up tool to implement the policies and targets set by the professional bodies and the UK government.

The study in this paper, using a literature review and survey fieldwork, has highlighted the similarity and differences in the perception and socio-cultural value system of British and British Asian households. From the outcome of the questionnaire survey, this paper examined two key aspects of Socio-economic preferences and energy behaviour.

The particular points are as follows:

1. Social perception and economic aspirations limit the acceptability of sustainable design and construction strategies. Questionnaire survey both in India and the survey conducted in Plymouth, the UK, clearly demonstrate that it is crucial to align household's aspirations in the process of developing sustainable housing strategies.
2. Difference in behaviour pattern in regulated and unregulated economy: there is a striking difference between the behaviour pattern of respondents in India and the UK. For instance, most of the sustainable features adopted by households in India were voluntary, whereas households in the UK had engaged in the features promoted by the policy or government in the UK.



3. Some consistence in the preferences for cultural values: one of the key findings is that social and cultural values scaffold the decision making process and households tend to emulate those preferences in migrated places, in spite of its inappropriateness; for instance, Vastu.

The research has shown that there is a direct correlation between the social and cultural values and energy behavior of households. Further examination of specific aspects like ventilation, heating would provide greater insight into the extent of impact of behavior on energy consumption and would go a long way in reducing the carbon emission and develop sustainable communities for the future.

## Reference

- BERRY, S. & DAVIDSON, K. 2015. Zero energy homes – Are they economically viable? *Energy Policy*, 85, 12-21.
- BERRY, S., WHALEY, D., DAVIDSON, K. & SAMAN, W. 2014. Near zero energy homes – What do users think? *Energy Policy*, 73, 127-137.
- CASTLES, S. 2000. *Citizenship and migration : globalization and the politics of belonging*, Basingstoke, Basingstoke : Macmillan.
- DANILOV-DANIL'YAN, V., LOSEV, K. & REYF, I. 2009. *Sustainable Development and the Limitation of Growth: Future Prospects for World Civilization*, Berlin, Heidelberg, Springer Berlin Heidelberg, Berlin, Heidelberg.
- DE WILDE, P. 2014. The gap between predicted and measured energy performance of buildings: A framework for investigation. *Automation in Construction*, 41, 40-49.
- DECC & TREASURY, H. 2015. Policy paper - 2010 to 2015 government policy: greenhouse gas emissions. Committee on Climate Change, Department of Energy & Climate Change: <https://www.gov.uk/government/publications/2010-to-2015-government-policy-greenhouse-gas-emissions/2010-to-2015-government-policy-greenhouse-gas-emissions>.
- DEEPIKA, M. 2008. *Interpreting Sustainability: examining the social approach to environmentally sustainable architecture in India*. Ph.D. thesis The University of Melbourne.
- ENERGAWARE. 2017. *EnerGAware project* [Online]. <http://www.energaware.eu/>. [Accessed 10 June 2017].
- FANGER, P. O. 1972. *Thermal comfort : analysis and applications in environmental engineering*, New York, New York : McGraw-Hill.
- FERNANDES, L. 2000a. Nationalizing 'the global' media images, cultural politics and the middle class India. *Media, Culture & Society*, 22, 611-628.
- FERNANDES, L. 2000b. Restructuring the new middle class in Liberalizing India. *Comparative studies of South Asia, Africa and Middle east*, 20, 88-104.
- FERNANDES, L. 2006. *India's new middle class: democratic politics in an era of economic reform*, Minneapolis, Minn., University of Minnesota Press.
- JONES, R. V., FUERTES, A., BOOMSMA, C. & PAHL, S. 2016. Space heating preferences in UK social housing: A socio-technical household survey combined with building audits. *Energy and Buildings*, 127, 382-398.

- KANNAN, S. & JANI, V. 2010. Role of Vaastu in Contemporary Residential Design. *Design Principles and Practices: An International Journal*, 4, 75 - 90.
- KHOURY, J., ALAMEDDINE, Z. & HOLLMULLER, P. 2017. Understanding and bridging the energy performance gap in building retrofit. *Energy Procedia*, 122, 217-222.
- KONSTANTINOU, T. & KNAACK, U. 2013. An approach to integrate energy efficiency upgrade into refurbishment design process, applied in two case-study buildings in Northern European climate. *Energy & Buildings*.
- MASLESA, E., JENSEN, P. A. & ASTMARSSON, B. 2013. Sustainable renovation of residential buildings and the landlord/tenant dilemma. *Energy Policy*, 63, 355-362.
- MENEZES, A. C., CRIPPS, A., BOUCHLAGHEM, D. & BUSWELL, R. 2012. Predicted vs. actual energy performance of non-domestic buildings: Using post-occupancy evaluation data to reduce the performance gap. *Applied Energy*, 97, 355-364.
- PAN, W. & GARMSTON, H. 2012. Compliance with building energy regulations for new-build dwellings. *Energy*, 48, 11-22.
- PATRA, R. 2009. Vaastu Shastra: Towards Sustainable Development. *Sustainable Development*, 17, 244-256.
- POWER, A. 2008. Does demolition or refurbishment of old and inefficient homes help to increase our environmental, social and economic viability? *Energy Policy*, 36, 4487-4501.
- SATISH, B. & BRENNAN, J. 2015. Significance of boundary conditions towards sustainable housing strategies: a case study of Mysore, India. *IAFOR Journal of Sustainability, Energy and the Environment*, 2, 21-40.
- SATISH, B. K. 2013. Sustainable housing futures for a growing middle class: a contextual study of Mysore, India. *Ph.D. thesis*. The University of Edinburgh.
- SATISH, B. K. Modelling energy use behaviour of British Asian households. Sustainable Earth 2017: A global forum for connecting research with action, 2017 Plymouth, UK. Plymouth University.
- SDC 2006. Climate Change – The UK Programme 2006: SDC response. <http://www.sd-commission.org.uk/>: sustainable development commission.
- SKEA, J. & NISHIOKA, S. 2008. Policies and practices for a low-carbon society. *Climate Policy*, 8, 5-16.
- SMITH, T. 2004. *Asians in Britain*, Stockport, Stockport: Dewi Lewis.
- TAHIR, F. & WALKER, I. 2013. Review of potential for carbon savings from residential energy efficiency. Cambridge: The Committee on Climate Change, Energy Saving Trust.
- THOMAS, W. D. & DUFFY, J. J. 2013. Energy performance of net-zero and near net-zero energy homes in New England. *Energy & Buildings*, 67, 551-558.
- TRUST, E. S. 2017. *Save energy at home* [Online]. <http://www.energysavingtrust.org.uk/>. [Accessed 15 Nov 2017 2017].
- WATERS, L. 2017. Energy Consumption in the UK: Overall energy consumption in the UK since 1970. In: DEPARTMENT FOR BUSINESS, E. I. S. (ed.).
- WHITE, E. 2012. Ethnicity and National Identity in England and Wales: 2011. Office for National Statistics: <https://www.ons.gov.uk/peoplepopulationandcommunity/culturalidentity/ethnicity/articles/ethnicityandnationalidentityinenglandandwales/2012-12-11>.

# Smart Sensing & POE for Heritage Buildings: A Comparison between Results of a POE Study and Actual Field Study Measurements for Evaluating Thermal Comfort in a Heritage Building

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**Abstract:** Smart sensing has been a term widely used in the field of thermal comfort in the past few years. However, this method holds a few barriers concerning the accuracy of the collected data. This paper introduces Post-occupancy evaluation (POE) as an additional tool for evaluating thermal comfort in occupied heritage buildings. POE acts as a supporting tool to increase the accuracy of the overall evaluation process. An office space within an occupied heritage building located in Downtown Cairo, Egypt was selected for the purposes of this study. The paper aims to compare results between a POE study and actual thermal measurements obtained from sensors installed in the office in order to evaluate thermal comfort and gain perspective for the purpose of evaluating the accuracy of the collected sensed data and provide a list of assumed barriers that might have caused the gap. Sensors were installed for 6 months during summer period collecting data for temperatures and humidity. The POE study was conducted through a survey questionnaire for occupants of the office space. Results of both were then compared determining the barriers causing lack of accuracy in the data collected.

**Keywords:** thermal evaluation, data accuracy, smart sensing, comfort level, Post-Occupancy Evaluation.

## Introduction

Heritage buildings represent a very sensitive asset of built-up areas. Accordingly, any work performed on them should be of a strong research background and with great sensitivity. Throughout the past decade, there has been a major shift in the climate. This Climate Change imposes a huge threat on our built cultural heritage, especially heritage buildings in use. This resulted in heritage buildings not being completely adequate to withstand the current climate, thus affecting the indoor thermal comfort. Therefore, the possible effects of climate change on heritage buildings and on the related indoor climate must be investigated. Many researches was dedicated to study the effect of Climate Change on the building IEQ in general (Fisk, 2015) (Nazaroff, 2013) (Brennan, 2016) (Holmes & Hacker, 2007), however heritage buildings were seldom the focus of the research. This research focuses on heritage buildings in specific giving that they are the buildings mostly affected by this change.

Evaluating indoor thermal comfort has made a huge difference in energy efficiency and adjusting human comfort levels over the years (Martinez et al., 2015) (Yang, Yan and Lam, 2014) (Rupp, Vásquez and Lamberts, 2015). Nowadays, smart sensing systems for thermal comfort evaluation have become a popular tool widely used to increase the efficiency of buildings' heating and cooling systems. However, it does bare some technical challenges and uncertainties about how accurate the data is. It is argued that these systems may increase the energy efficiency but they often fail to achieve a thermal comfort level

satisfying for the occupants (Barrios and Kleiminger, 2017). Thermal comfort has been described by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) as “that condition of mind that expresses satisfaction with the thermal environment” (ASHRAE, 2010). Therefore, in order to be able to fully evaluate the thermal comfort of a building, occupant’s feedback and satisfaction is of outmost importance. Post Occupancy Evaluation (POE) is the process of obtaining feedback on a building’s performance in use. It is often used to evaluate the performance of new structures once occupied in order to obtain feedback on whether the building is performing as expected or not. In this research, POE is employed as an undemanding tool for evaluating occupants’ satisfaction levels with thermal comfort. The main of this research is to investigate the barriers and challenges of using smart sensors in evaluating thermal comfort through comparing results obtained from both evaluation methods used; data obtained from smart sensors for temperatures and humidity and POE questionnaire.

### ***Case Study History***

The case study adopted is an apartment in a heritage building that was retrofitted into an office space. The office belongs to the Cairo Lab for Urban Studies, Training and Environmental Research (CLUSTER) and is located on the 3rd floor of a mixed-use heritage building.



Figure 1 Rabbat Building (CLUSTER Team, 2017)

The case study building is located in Downtown, Cairo which is considered the heart of Cairo City. The area dates back to the late 19th and early 20th century and was designed by some of the most prestigious architects in France. They were commissioned by Ismail pasha during his visit to Paris. The area was once the home of the prosperous elite in Cairo. However, years of neglect followed by Cairo’s great fire incident in the 1950’s have led to the decay of the building’s exterior. The case study building is called ‘Rabat’ and was designed by architects Léon Azéma, Max Edrei and Jacques Hardy. It was built between 1927-1930. The building is named after the capital city of Morocco.

### ***Methodology***

Two methods were applied as analytical approaches to best evaluate thermal comfort within the office space and achieve the research aim. The first method is obtaining readings for temperature and humidity from smart sensors installed in the office space throughout the study period and analyzing the data obtained to indicate thermal comfort level in the

office space. The second is a POE survey questionnaire to obtain occupants evaluation about thermal comfort. The POE study questions were oriented towards detecting occupants' satisfaction level with thermal comfort in the studied workplace.

### **Smart Sensors**

Measurements for the thermal condition of the internal environment of the office space were carried out through the installation of low cost sensors which measures the temperature and humidity; Temperature & Humidity Sensors (PIR). In order to be able to obtain an accurate evaluation of the physical environment, an analysis of how occupants use the space needed to be done in order to identify which spaces are active and which are not as active. This made it possible to take decisions about which rooms need sensors (since there were limitations with number of sensors available). The number of occupants using each space and the frequency of its usage was analyzed in Figure 3.

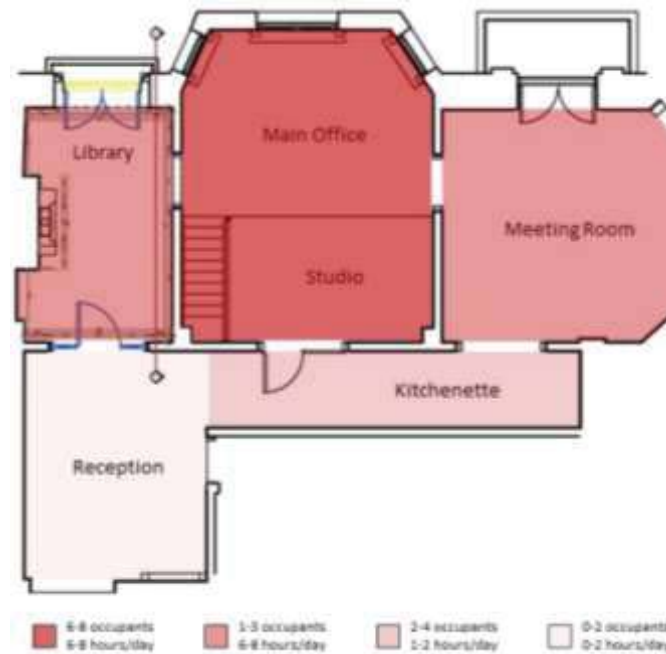


Figure 2 Occupant Space-Use Analysis

Sensors were distributed among the office spaces according to the results of the occupant space-use analysis. These sensors were installed and set-up to provide readings every two minutes. In order to obtain accurate results from the sensors, certain specifications for their installation were to be considered. PIRs measure the temperature and humidity, in addition to detecting occupancy movement. Therefore, they had to be installed at an appropriate height that suits human height level in order to be able to detect movement. Hence, PIRs were installed at a range of 1-1.5 m height. In addition, they had to be installed away from direct sunlight and all other heat gains. Positions of sensors installed on floor plan and samples of how they were installed are represented in Figures 3 and 4.

The data obtained from each sensor is sent to a Monitoring Unit Hub connected wirelessly to the sensors and stored in a Zigbee Dongle USB. The data is then sent to the live website where analysis of this data through graphs is possible. Data collected for this paper is of a 6 month sensing period starting from 1st of March to 31st of August, 2017.



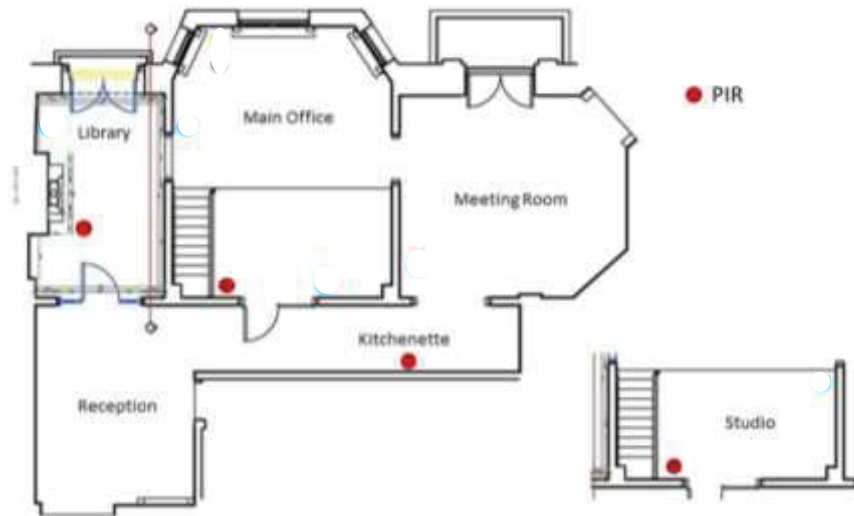


Figure 3 Sensor places on floor plan



Figure 4 Samples of the sensors installed

## POE

Post-occupancy evaluation (POE) is a platform for the systematic study of buildings once occupied, so that lessons may be learned that will improve their current conditions. The concept of POE was first introduced in the 1960's (Preisner, Rabinowitz, & White, 1998). POE studies mainly focus on the occupants' degree of acceptability and satisfaction with the building performance and their surrounding environment including the indoor environmental quality, thermal, visual, lighting and acoustic comfort. It also includes occupants' evaluation about functional aspects of the building such as spatial relations and comfort, HVAC efficiency, communications and other type of equipment efficacy, building circulation and accessibility, energy consumption and energy sources, etc. Since this study aims to evaluate thermal comfort level, the POE evaluation will only focus on occupants' satisfaction and comfort with the thermal environment.

HEFCE et al. (2006) recognized POE as a process that can be applied to any type of building. This process comprises seven steps: (1) Identify aim of the POE; (2) decide on which approach; (3) brief for the POE; (4) plan the POE; (5) carry out POE; (6) report on findings; (7) take action in response to findings. In addition, POE usually falls under the following classification: Indicative POEs, which gives an indication of major strengths and weaknesses of a particular building's performance; Investigative POEs, which goes into more



depth of the causes and effects of issues in building performance; Diagnostic POEs, which correlates physical environment measures with subjective occupant response measures.

The scope of this paper falls within the Diagnostic POEs in which the occupants' subjective views about the physical milieu of the workplace are measured and compared to actual thermal readings obtained from sensors installed. In addition, this research only includes the first six steps of the POE seven-step process.

## Analysis and Findings

### POE

The office consists of 20 occupants and they were all asked to answer the questionnaire subjectively. Occupants normally spend 8-12 hours in the office. All of the occupants of the office were desk based and the office arrangement consists of low-occupancy plan rooms. Respondents aged range from 20 to 40 years old. 65% are female while 35% are male respondents. The questionnaire was self-administered and included occupants giving their evaluation of thermal comfort and humidity level during summer time. The Likert-Scale consists of 7 numerical nomenclatures indicating the responses given on occupant's thermal comfort based on their thermal sensation, which ranges from '-3' to '3'. Results are represented in Figures 5 and 6.

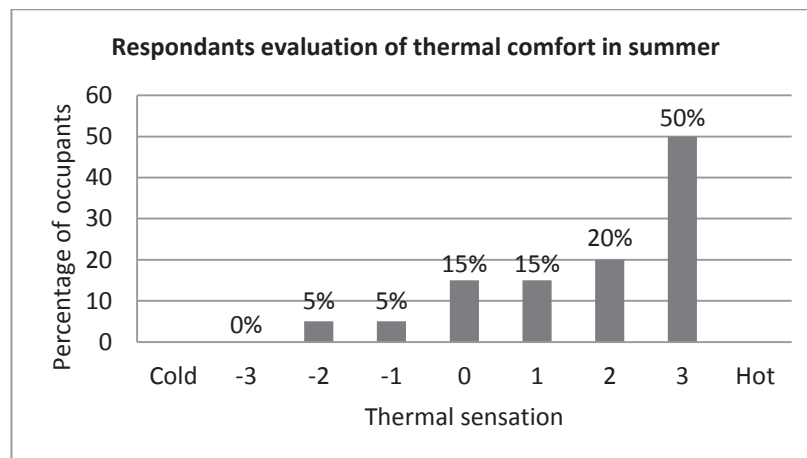


Figure 5

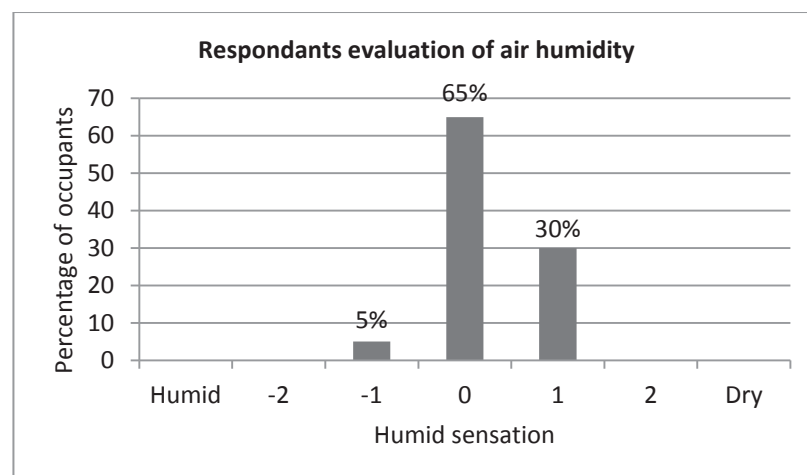


Figure 6

Based on results demonstrated in Figures 4 and 5, it is clear that 50% of the occupants feel discomforted with the how hot the office gets in the summer. As for the humidity, 65% of the occupants have a neutral feeling about the humidity level in the office. Moreover, the questionnaire also included asking the occupants about their opinions with other aspects. Responses indicated that 50% of the occupants feel that the Library and Studio are spaces with highest thermal discomfort level.

### **Data from sensors**

Thermal comfort evaluation was carried out through analyzing data from the sensors for temperature and humidity respectively for each space (Figures 7 and 8). A psychometric chart was used to plot the data for monitoring thermal comfort where results were compared to the thermal comfort zone determined by ASHRAE Standard 55-2013 (Figures 9 to 12).

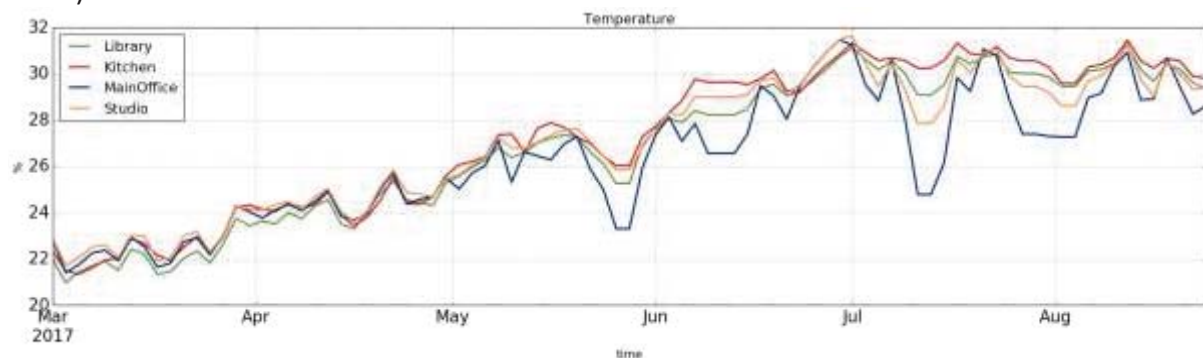


Figure 7 Daily average temperatures from March till August. 2017.

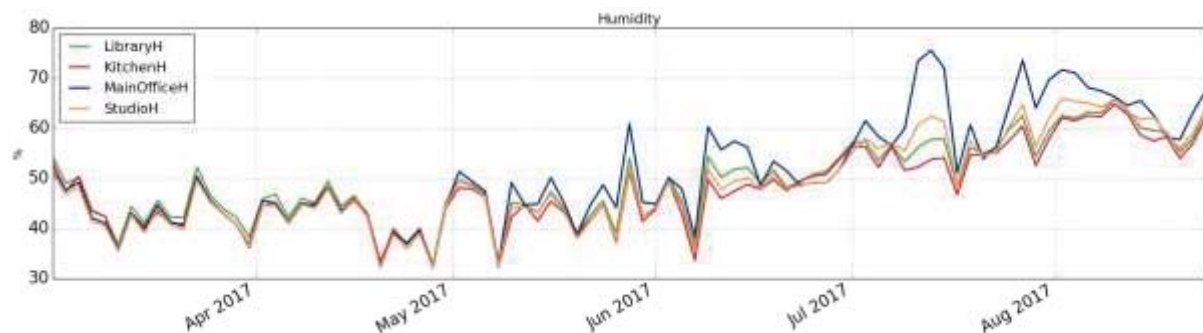


Figure 8 Daily average readings for Humidity from March till August, 2017.

Note that the office space is both mechanically and naturally ventilated.

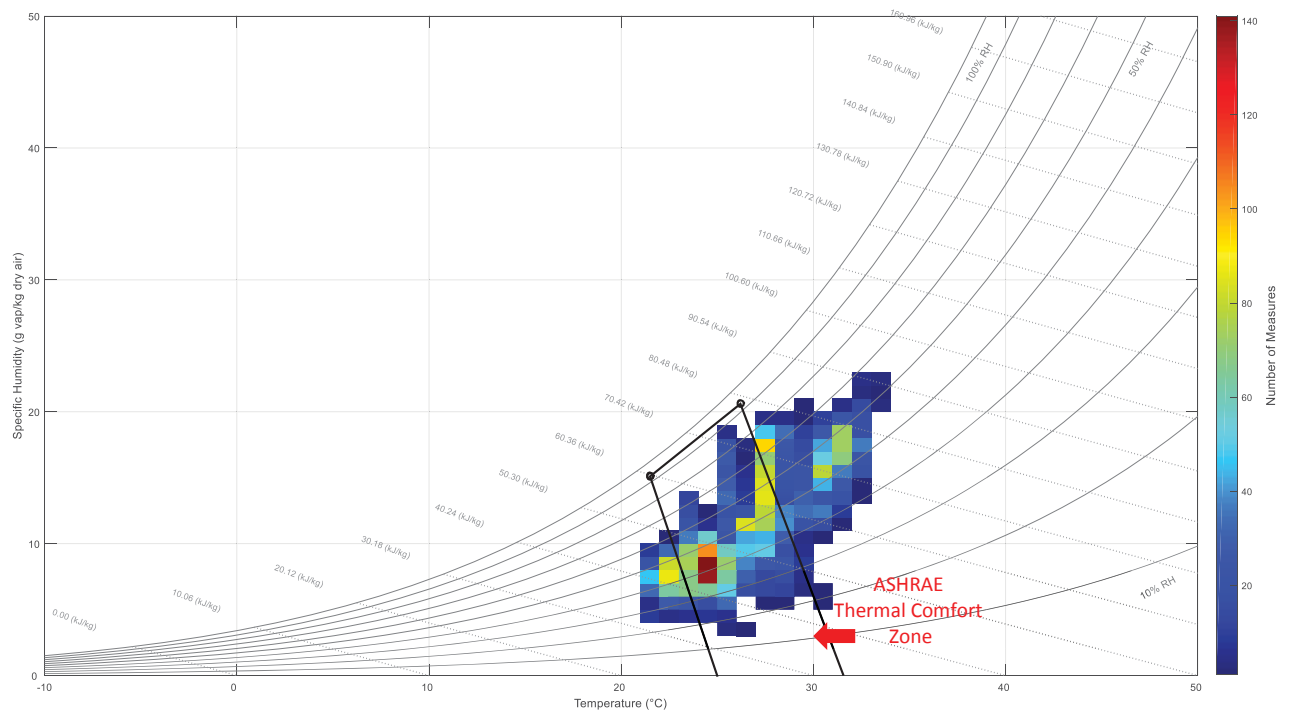


Figure 9 Monitoring of library space – data plotted on an hourly basis

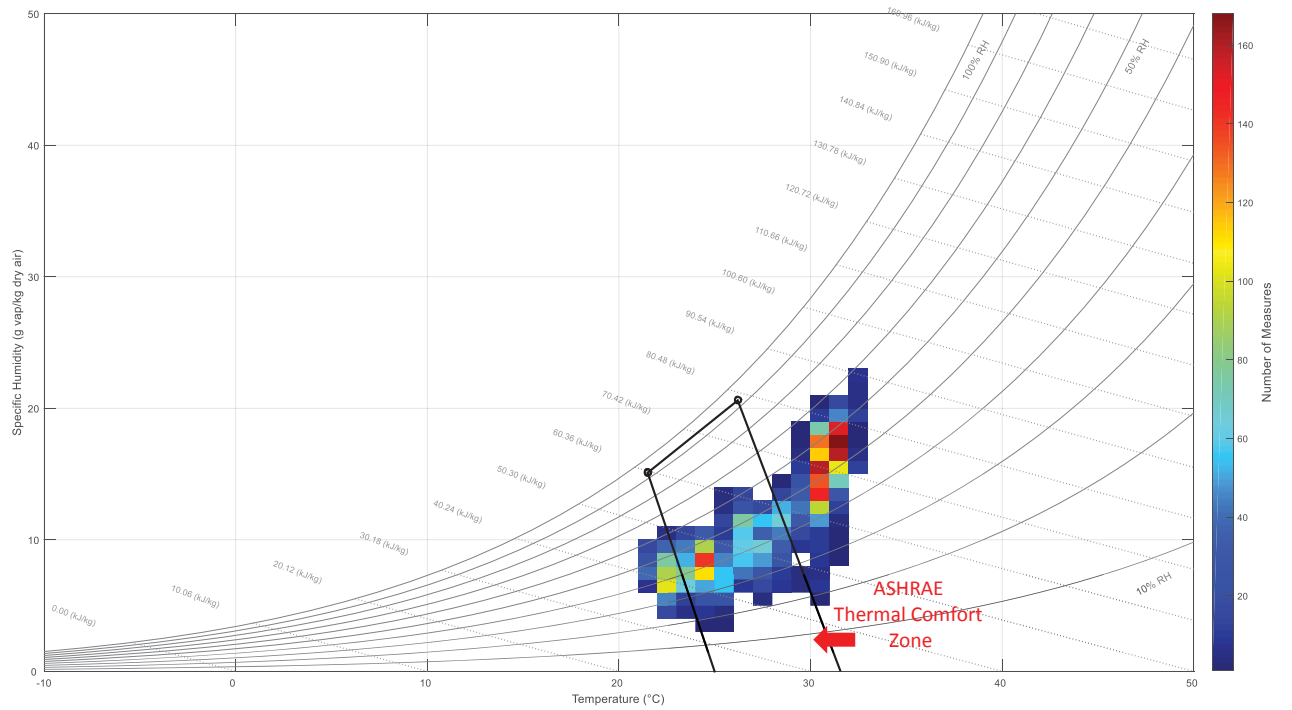


Figure 10 Monitoring of kitchen space – data plotted on an hourly basis

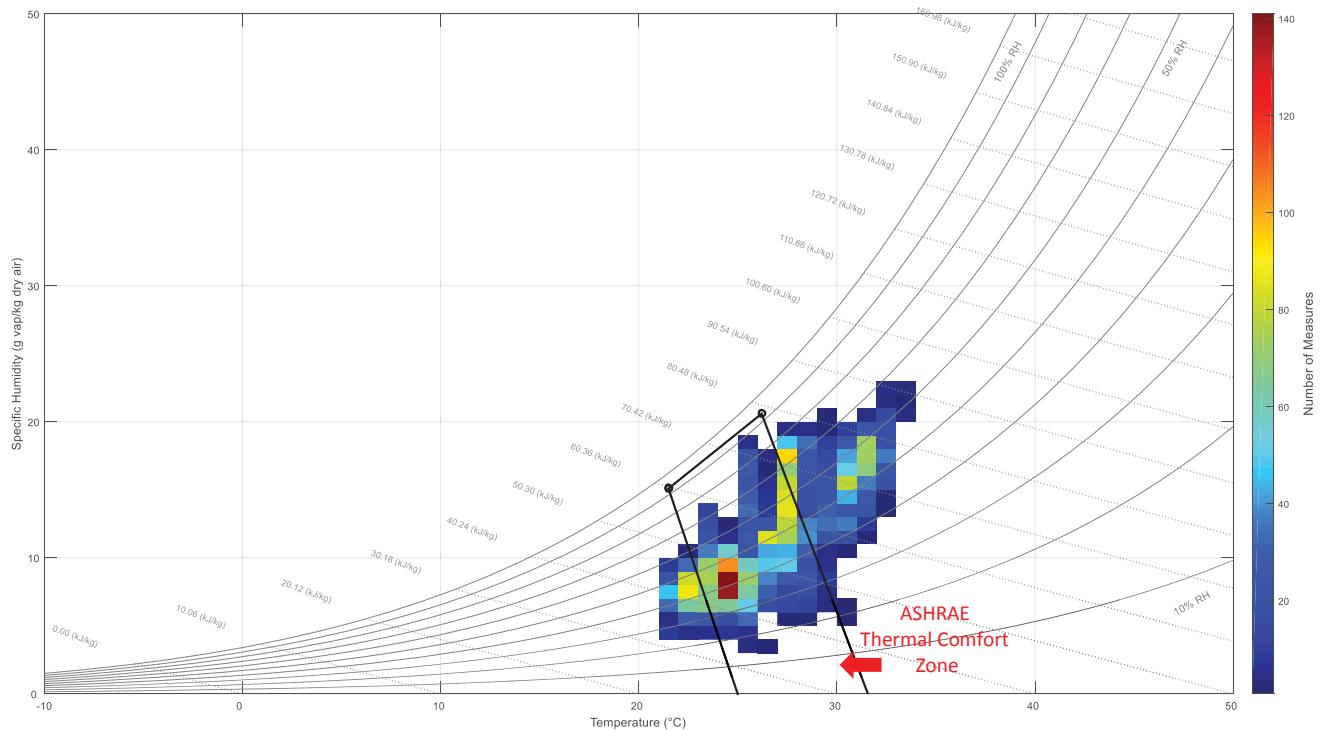


Figure 11 Monitoring of main office space – data plotted on an hourly basis

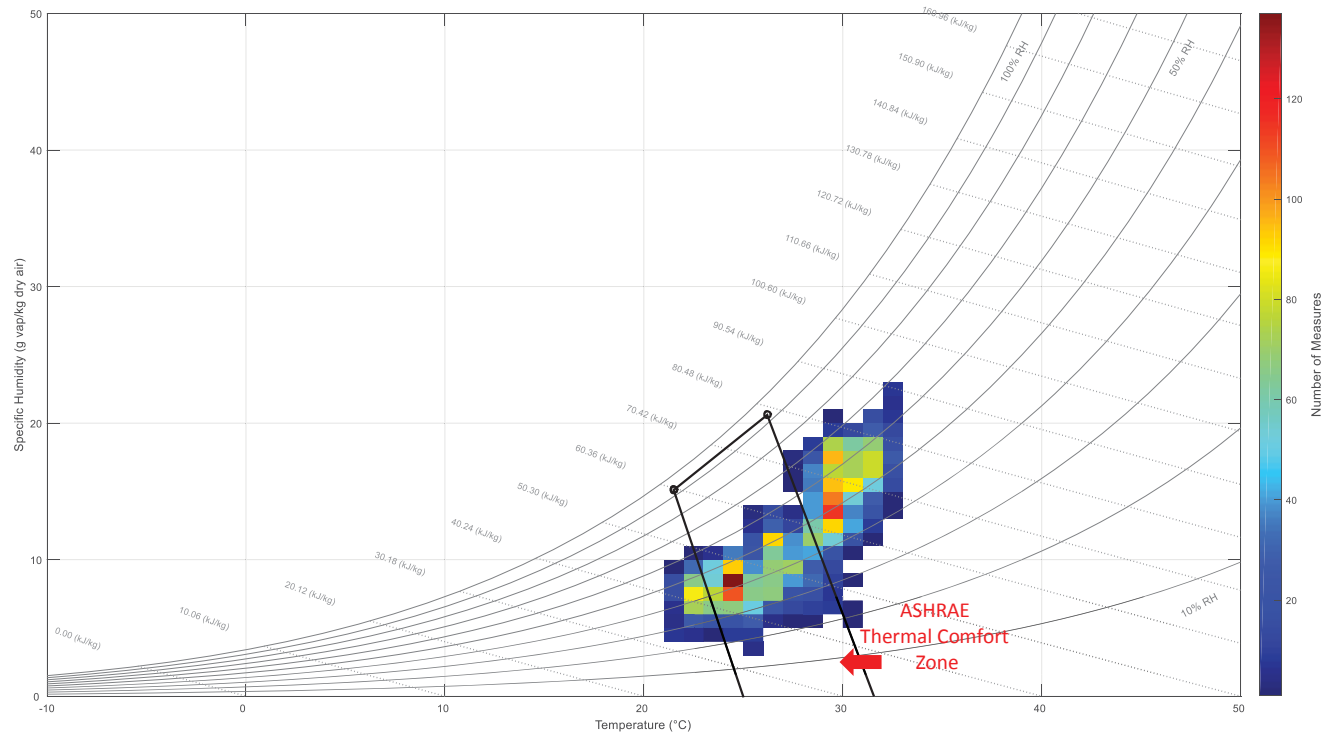


Figure 12 Monitoring of studio space – data plotted on an hourly basis

Based on the graphical analysis presented and results from the POE study, thermal comfort outcomes seem to be consistent for both evaluation methods. Thermal readings indicate high temperatures exceeding the comfort level which was verified by occupants' responses indicating sensation of discomfort with thermal level. However, graphical analysis indicates very high humidity levels which are not consistent with occupants' responses about comfort levels with humid sensation. In addition, data extracted from sensors for plotting indicate presence of error in readings at times; unreasonable values or 0 values which were accordingly excluded from plotted data.

The above mentioned indicates that there is a major problem with the data accuracy. Such inaccuracy can be caused by barriers facing the smart sensing system installed. Such barriers are often in the form of technical barriers or barriers caused by the presence of environmental or physical barriers not taken into consideration. Predicted barriers causing data inaccuracy for the smart sensing system applied are as follows:

➤ Barriers of installation

- Limitations in location and position of sensors due to need of proximity to electrical plugs.
- Limitations caused by office furniture distribution.
- Inappropriate sensor fittings causing sensors to sometimes fall out of position possibly causing damage.

➤ Technical barriers

- Manufacturing errors
- Failure in internet connectivity
- Power cuts
- Accidental unplugging of sensors or monitoring unit

## **Conclusion and Recommendations**

In conclusion, thermal comfort evaluation has evolved a great deal with the help of smart sensing systems. However, the possibility of inaccurate data due to unclear barriers creates some difficulties. In this research, an in-field investigation methodology on thermal comfort was applied on an office space study sample in a heritage building. The research used two approaches for thermal evaluation including both the physical and human aspect. The first was measuring thermal parameters influencing comfort level using low-cost live-data sensors. The second was a POE oriented questionnaire survey obtaining occupants' satisfaction with thermal comfort. This study aimed at not only evaluating thermal comfort but using different approaches to it for the aim of comparing results and gaining perspective on the efficiency and accuracy of data provided by the sensing system. Consequently, a few barriers were determined as a possibility behind inaccuracy of data.

Since occupant satisfaction is a very important aspect of achieving sensation of comfort, POE should be considered an important and essential part of any thermal evaluation process. It is important to validate results of monitoring thermal comfort with occupants' views on their physical condition. Moreover, it provides a good insight on underlying variables that might be affecting thermal comfort levels.

## **Acknowledgments**

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## References

- ASHRAE (2010) 'Thermal environmental conditions for human occupancy', no. ANSI/ASHRAE Standard 55-2010.
- Barrios, L. and Kleiminger, W. (2017) 'The Comfstat – Automatically sensing thermal comfort for smart thermostats', 2017 IEEE International Conference on Pervasive Computing and Communications, Kona, HI, USA.
- Brennan, T. (2016) 'Climate Change: Impact on Building Indoor Environmental', 14th Annual Green Building Conference, New York.
- English Heritage (2008) Heritage Definitions, [Online], Available: <https://historicengland.org.uk/advice/hpg/hpr-definitions/>.
- Fisk, W.J. (2015) 'Review of some effects of climate change on indoor environmental quality and health and associated no-regrets mitigation measures', *Building and Environment*, pp. 70-80.
- Green Building 101 (2014) 'What is Indoor Environmental Quality?', *Green Building 101*, 11 June, Available: <http://www.usgbc.org/articles/green-building-101-what-indoor-environmental-quality>.
- Holmes, M.J. and Hacker, J.N. (2007) 'Climate change, thermal comfort and energy: Meeting the design challenges of the 21st century', *ELSEVIER: Energy and Buildings*, pp. 802-814.
- Martinez, F.J.R., Chicote, M.A., Penalver, A.V., Gonzalez, A.T. and Gomez, E.V. (2015) 'Indoor air quality and thermal comfort evaluation in a Spanish modern low-energy office with thermally activated building systems', *Science and Technology for the Built Environment*, pp. 1091-1099.
- Nazaroff, W.W. (2013) 'Exploring the consequences of climate change for indoor air quality', *Environmental Research Letters*.
- Pati, D. and Pati, S. (2013) 'Methodological Issues in Conducting Post-Occupancy Evaluations to Support Design Decisions', *HEALTH ENVIRONMENTS RESEARCH & DESIGN JOURNAL*, vol. Conducting Post-Occupancy Evaluations, no. Research Methods, pp. 157-163.
- Preisner, W.F.E., Rabinowitz, H.Z. and White, E.T. (1998) *Post-occupancy Evaluation*, Van Nostrand Reinhold.
- Rupp, F., Vásquez, G. and Lamberts, (2015) 'A review of human thermal comfort in the built environment'.
- Yang, L., Yan, H. and Lam, J.C. (2014) 'Thermal comfort and building energy consumption implications – A review', *ELSEVIER: Applied Energy*, pp. 164-173.



*Chapter 3:*  
*Bioclimatic and passive design*  
*Energy efficiency in buildings*  
*Zero and low carbon design*

# Built Form Driven Effects on the Urban Microclimate of Neighbouring Buildings and Streets - City of London Case Study

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## Abstract:

Taking the City of London as a case study area this paper reports on an early investigation into the direct influence of built form at both the building and neighbourhood scale, on the winter urban climate, and reports on a preliminary investigation into how built form influences passive resources i.e., solar access, wind and ventilation, which in turn influences climate sensitive design. This paper reports on a series of preliminary microclimate measurements taken between December 2016 to February 2017 along the route of an established urban climate walking tour in and around the City of London. The route takes us through a series of urban streets and public spaces where we experience first-hand the direct influence of building and urban form on air, surface and near surface temperatures, wind speeds and air quality. Whilst the walk offers a novel perspective on the City's dramatic and changing skyline, the microclimate measurements offer a more detailed analysis of the urban climate trends that result from the variations in built form found along the route. The aim of this research is to provide this level of detail and to demonstrate the long-term benefits of a 'form' first approach required to achieve sustainable urban development through climate-sensitive urban planning.

**Keywords:** Urban climate, microclimate, net-energy effects, interdependent effects, built form

## Introduction

Buildings consume the largest portion of all global energy use, therefore produce the largest share of energy driven greenhouse gas emissions. As a result, sustainable urban development focuses on lowering regulated energy (fixed consumption inherent to the buildings fabric and conditioning systems), and the supply of energy through renewables. However, buildings are often placed in an urban setting, where increasing urban density reduces accessibility to passive resources, impacting on the background climate and in turn buildings energy needs. On the other hand, higher urban densities offer the possibility of improved efficiency over non-urban environments ( $\text{CO}_2/\text{m}^2/\text{capita}$ ) (Breheny, 1992; Jabareen, 2006), although, due to the hereditary nature of urban morphology, modifying infrastructure to accommodate higher densities is not straightforward. As a result, these two sustainable design principles, 'high density & passive design', are becoming increasingly at odds with one another, where the needs of one building often over-rides that of another; for example, a tall building casting shadows over a solar array, or increasing the heating loads to an underlying residential area. Then again, clusters of tall buildings have the potential to provide mutual shading, lowering cooling loads, yet these built form net-energy effects are not accounted for (Fitcher et al 2017).

However, whilst adopting these generic approaches many new buildings achieve impressive energy credentials, they neglect the far reaching and dynamic built form driven energy outcomes both in its natural expressions (temperature/wind/ sunshine) and those of building needs (cooling/heating loads) and how these are interdependently linked at the scale of the city street; Built form is recognised to alter nearly every aspect of natural energy, hydrological, and circulation systems yet these built form effects are often overlooked to accommodate an increased need for floor area, and whilst this oversight may result in part from the lack of a suitable framework that accounts for these interdependent energy relationships, the consequences are serious, by focusing on generic methodologies to reach

target reductions are we missing the long-term opportunities required for sustainable urban development that could be achieved by taking a 'form' first approach to urban development at a scale larger than the individual building? The work presented here represents a preliminary study into the early stage development of a framework that accounts for these interdependent built form effects to aid sustainable urban development and urban resilience in a climate sensitive manner.

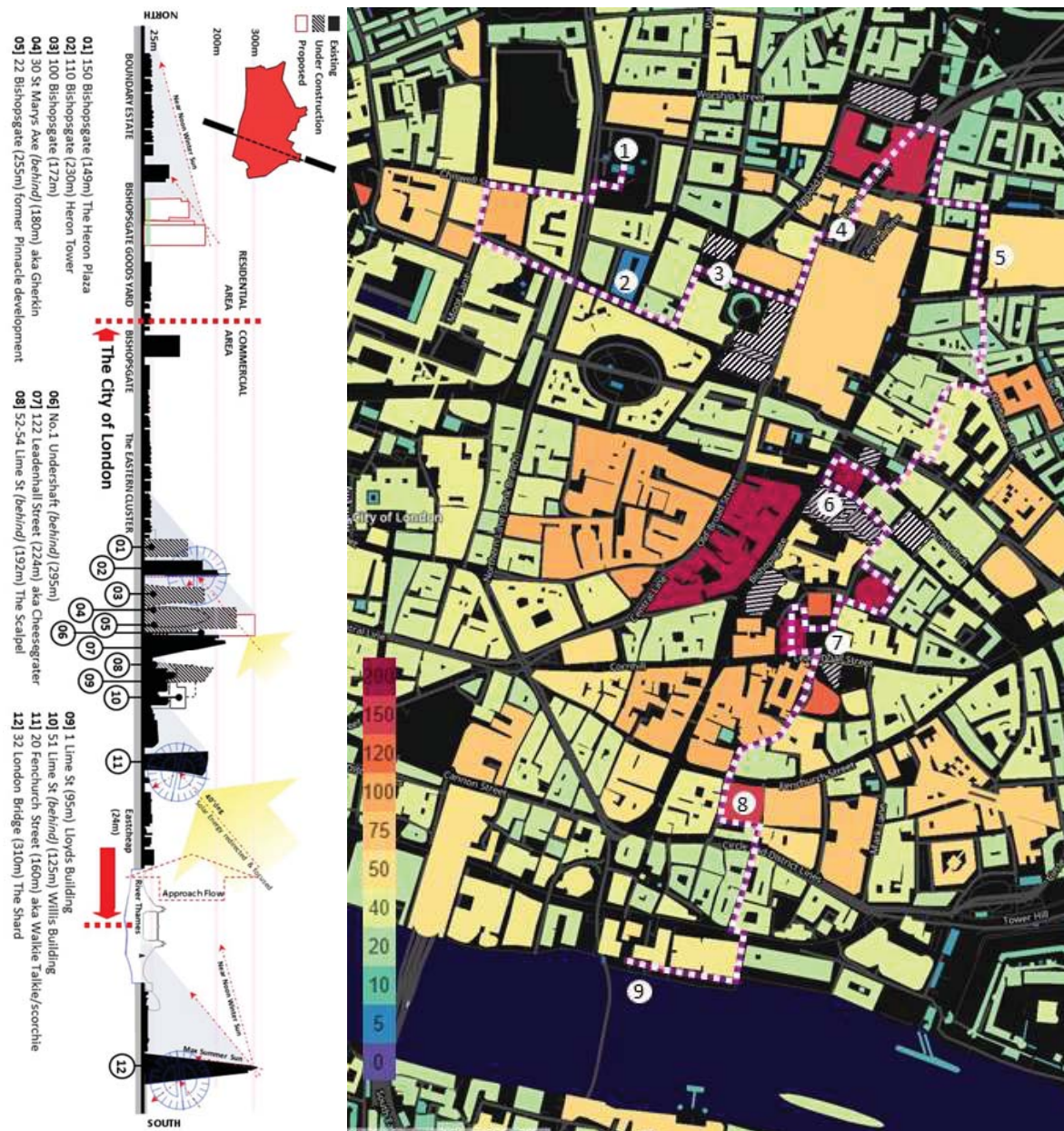


Figure 1 – Section through Eastern Cluster City of London showing location of tall buildings and figure ground showing building heights (hatched areas are buildings currently under construction) emu-analytics and main data collection points 1) Finsbury Square 2) Eldon Street 3) Broadgate Circus 4) Exchange Square 5) Spital Square 6) Broadgate 7) Eastern Cluster 8) Fenchurch Street and 9) River Thames Walk

This paper reports on a series of preliminary microclimate measurements taken between December 2016 to February 2017 along the route of an established urban climate walking tour in and around the City of London (CIBSE Journal 2015). The route takes us through a series of urban streets and public spaces where we experience first-hand the direct influence of building and urban form on air, surface and near surface temperatures, wind

speeds and air quality. Whilst the walk offers a novel perspective on the City's dramatic and changing skyline, the microclimate measurements offer a more detailed analysis of the urban climate trends that result from the variations in built form found along the route.

The City of London (the City) is both Greater London's historic core and a world leading financial and business district. These parameters mean that whilst the City is required to retain much of its medieval layout, it must also accommodate an ever-increasing demand for high end office space within its limited footprint (2.9 km<sup>2</sup>). Further constraints on building form includes height restrictions to ensure safety for overhead aeroplanes, view corridors protecting views of St Pauls and the Tower of London, and easements such as right to light. Together these have given rise to in an emerging morphology of tall and very tall buildings (>150) often with unusual forms being inserted into a low-lying setting (<25 m). The resultant urban form and the proximity of the building surfaces to each other has created some extreme microclimates. However, as the City's function has developed around trade and commerce<sup>1</sup>, the requirement to provide comfortable outdoor and green space is mostly limited to providing comfortable lunchtime activities for office workers, minimising concerns over reduced solar access and higher windspeeds, particularly off tall buildings when compared to areas with a residential function. It is worth noting, that whilst the impact of built form effects on the surrounding climate can be positive, what is best for office buildings may not be best for residential buildings, where outdoor activities extend beyond lunchtime hours, particularly in winter.

Despite its office (trade and commerce) function the City's emerging typology (increasing urban density particularly in terms of increased building height) is representative of many urban areas both nationally and international, where the urban form is undergoing a massive transformation. Yet these remarkable changes in the urban landscape are proceeding without any overall guidance or assessment of the aggregate impact. Instead, each building is evaluated on its own, stand-alone merits, with little consideration for their wider impact, currently outside the broader discussion on sustainable urban development. To date, focus falls on the density and economic arguments; with the effects of building and urban form limited to a consideration of aesthetic values i.e., views corridors, and/or impact assessments. It is important to note the permanence of building form and the consequential long-term impacts of these built forms on the surrounding setting (>50 years).

### ***The Urban Climate***

Whilst the significance of built form effects on the urban climate has been acknowledged, for the most part these effects fall outside the broader discussion on sustainable urban development. Instead, the effects of building and urban form are often limited to a consideration of aesthetic values i.e., views corridors, and/or impact assessments i.e., rights to light and changes to the wind field. A current example of this oversight is the public debate on the 455+ proposed tall buildings (20 storeys or more) that will transform London's skyline. The debate focuses on the aesthetic, density and economic arguments. Yet the urban morphology that will emerge will have significant long-term impacts on the existing outdoor climate alongside the ambient environment of other buildings.

Whilst there are various outcomes of built form on the background climate, in general the most significant difference result from the way heat is stored and released. Urban areas tend to heat up and cool down slower than their neighbouring non-urban area, and research

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<sup>1</sup> The City has a relatively low residential population, around 8000, compared to a large transient working population, around 450,000 (City of London, 2011)



has shown (LUCID) that London's urban heat island (UHI), the most widely recognised urban climate effect, is a predominantly nocturnal, and is reported to reach intensities up to 8K (Watkins, 2007). London's UHI, although dynamic, corresponding to the underlying urban form where the thermal centre is shown to be situated in and around the City, the tallest and most dense part of greater London, where daytime air temperatures found to be equal or lower to those of the background setting (Bohnenstengel et al 2011). These effects are less pronounced with distance from the city centre. However, the urban microclimate remains a more complex matter.

Urban microclimates are shown to vary in intensity at different times of day and year, and includes changes to: air and surface temperatures; direct and diffuse solar irradiation levels on both horizontal and vertical surfaces; wind speed and direction and air quality, and can vary significantly over very short distances (<1 m). The strength of these effects is dependent on many factors including: the background climate conditions; the choice of construction materials; whether the land is paved or vegetated; the dimensions and situation of the surrounding area, and most importantly its morphology, alongside the activities carried out within the setting. Yet despite the effects of the built form on local climate, thermal comfort and energy consumption have been researched (e.g., Olgyay's 1963; Givoni, 1998; Knowles, 1981; Emmanuel, 1993; Steemers et al 2000; Ratti et al, 2003; Ratti et al, 2005; Fitcher, et al, 2013; Martins et al, 2014; Fitcher et al, 2017), the requirement for microclimate assessments are limited to daylight/sunlight/shadowing (permanent and transient), light pollution (glare/solar glare, sky glow, light trespass, light ingress) and under certain conditions wind assessments overlooking the far reaching and interdependent effects of built form the ambient conditions of neighbouring buildings and streets.

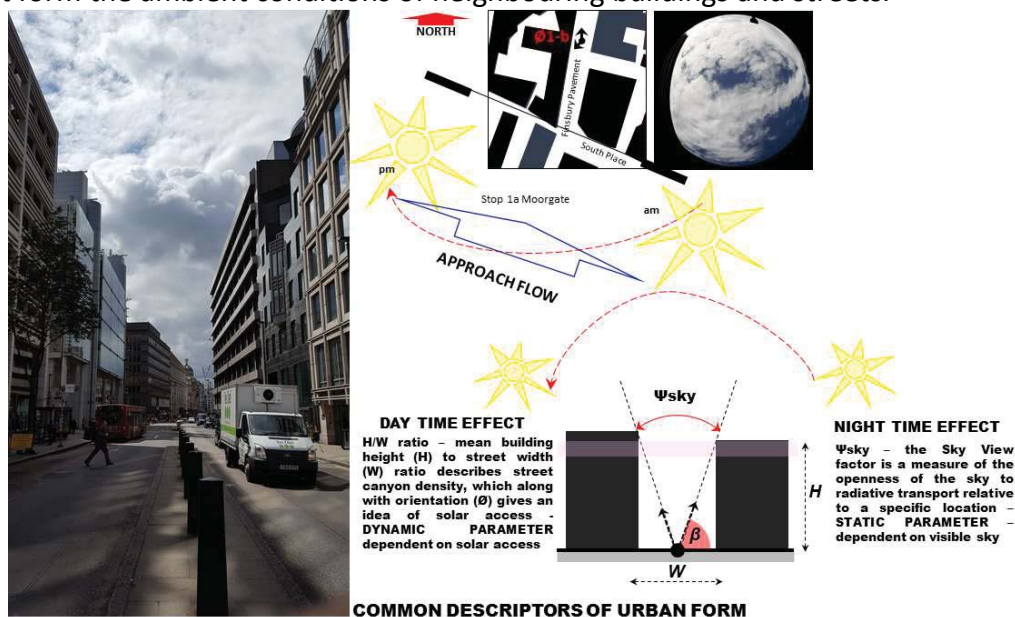


Figure 2 Looking south along Finsbury Pavement towards Moorgate. Figure Ground of base location showing urban configuration over 50 m<sup>2</sup>, sun path and dominant direction of approach flow. Fisheye lens photo showing nearly complete view of sky. Both sky view factor and mean H/W ratio are common descriptors of urban form recognised to influence energy exchanges within the urban canyon.

### Case Study Area

Whilst a detailed description of the various configuration found along the route are outside the scope of this paper, the route leads us through typical street configurations (figure 1), both of modern terraced buildings of similar height (25 m) and construction (Stone finish with

high glazing ratios), through open spaces in the form of public squares both vegetated (location Ø1) and unvegetated (locations Ø3, Ø4, Ø5 and Ø7), and narrow medieval street layouts (<10 m), down to the bank of River Thames (Tidal). The route is peppered with a selection of increasingly tall and buildings (>150 m increasing in height to 230 m) (listed figure 1). Most of the route is free of vegetation and acts as thoroughfares and is heavily congested with both traffic and pedestrians.

The case study area covers a broad range of built form driven energy outcomes, these include, but are not exclusive to, thermal control, overall environment, health and wellbeing (including air quality) and urban sustainability and resilience. Each of these spaces and the connecting streets represent urban configurations that can be found in a variety of cities around the world, but each are unique in terms of their function (level and type of activity) and their latitude.

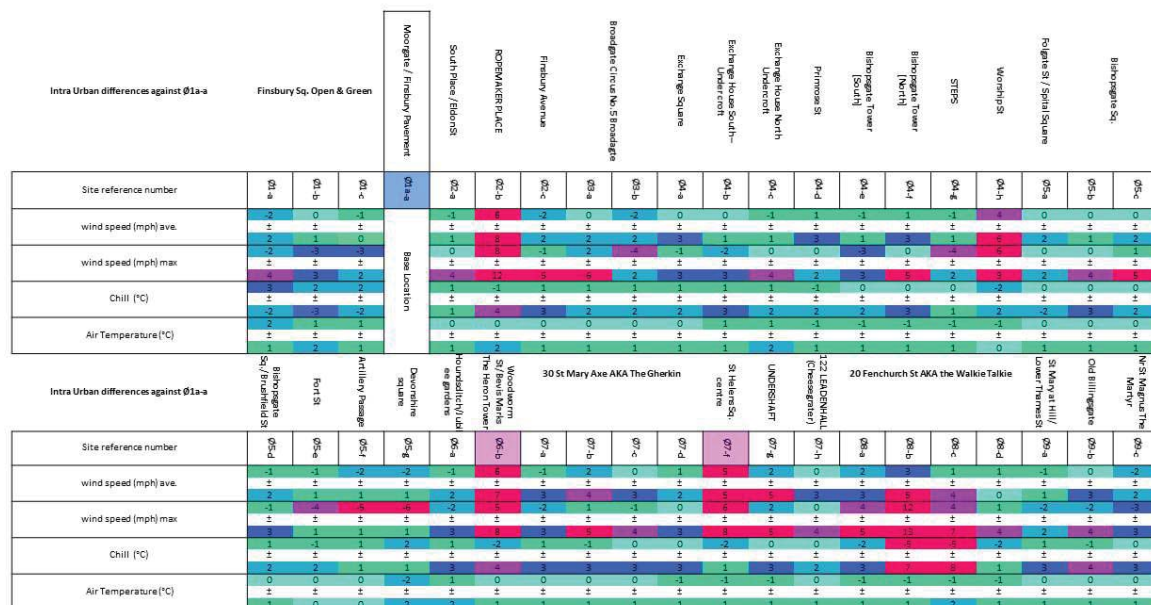


Figure 3 Results from 54 locations as a range in variations against Moorgate / Finsbury Pavement Ø1a-a

## Methodology

Results are presented as variations against the base location Finsbury Pavement [Ø1a-a] (figure 2). The results are presented in this way to represent trends rather than actual measurements. The base location is located at the north end of Moorgate, a North/South thoroughfare with a mean building height to street width (H/W) ratio close to 1. The location was chosen as not only does it represent many urban streets that can be found in a range of cities, but also represents typical urban climate text book scenario in terms of its symmetrical terraced configuration, with all buildings of similar height (25 m) and construction (Portland stone with high levels of glazing), and runs parallel to the dominant south west wind approach, it is worth noting the street is void of vegetation. Readings also showed this location to represent the average conditions of the case study area.





Figure 4. Top Air temperature and Chill factor; Range of differences against the base location 1a-a marked by the red circle. The range of differences can be in the key in the top left-hand corner. The closer the colour of the reading is to green the smaller the difference. The darker colours represent the larger the range in difference.

Measurements were taken in the afternoon, regularly over the winter period at 54 different locations along the route. Data was collected for air temperature (°C) and chill factor (°C) (figure 4), wind speed maximum (mph) and wind speed average (mph) (figure 5), using a Kestrel 3000 at six different afternoons between 2 and 5. Each afternoon was chosen to represent different typical afternoon weather conditions for this time of year. At each location, the device held at arm's length facing north, at approximately 1.2 meters above the ground, at an equal distance between buildings. The readings were taken once the device had stabilised, which was turned off between readings.

### *Results and Discussion*

A series of readings were taken along the route (marked in green figure 4 and 5) and were compared against the base location Ø1a-a. The readings represent the range in difference conditions, but demonstrate some predictable built form driven climate characteristics. For example, for location Ø2b the base of Ropemaker Place a small cluster of relatively tall buildings (96 m) compared to their surroundings, air temperature differences were small within  $0\pm2$  against the base location Ø1a-a, yet, large variations in wind speeds  $8\pm12$  were found (figure 6). These differences result in a high chill factor variation of  $-1\pm4$  which impact significantly on thermal comfort. These results confirm much urban climate research which suggests that with windy conditions, such as those found in winter, air temperatures are likely



to be similar throughout the urban area due to local scale mixing. There are many examples of similar built form effects that can be demonstrated throughout the results.



Figure 5. Average wind speed and maximum wind speeds. As to figure 3 the variations in colour represent the range of readings

Chill factor on the other hand demonstrated a much larger range. For example, site Ø2b has a chill factor range against 1a-a of  $-1\pm4$ , whilst Ø1a has a range of  $3\pm2$ . The largest chill factor range was found at the base of 20 Fenchurch St the north/west corner Ø8a  $-2\pm3$ ; the south/west corner Ø8b  $-5\pm7$ ; the south/east corner Ø8c  $-5\pm8$ ; and the north/east corner Ø8d  $-2\pm1$ . These results correspond with both average and maximum wind speed the north/west corner Ø8a  $2\pm3$ ,  $4\pm5$ ; the south/west corner 8b  $3\pm5$ ,  $12\pm13$ ; the south/east corner Ø8c  $1\pm4$ ,  $3\pm7$ ; and the north/east corner Ø8d  $1\pm0$ ,  $1\pm4$  respectively. These differences between average and maximum demonstrate the gusty nature of wind especially off tall buildings, alongside the sheltered condition of the north/east corner.

The performance of the form of tall buildings and the proximity of the surrounding buildings to be important. Location Ø7a, Ø7b, Ø7c and Ø7d at the base of 30 St Mary axe, aka the Gherkin, is a comfortable area in all conditions, whilst St Helens Square Ø7f at the base 122 Leadenhall aka The Cheese grater and the Aviva Tower are uncomfortable for a significant about of the time.

All air temperature differences were found to be minimal, within a similar range of the base site or lower. This can be seen by the small range of colour difference shown in the figure ground image (figure 3 & 4). Although small, the largest air temperature difference was found at location Ø1a  $2\pm1$ , a sheltered hard standing location at Finsbury Square Gardens.



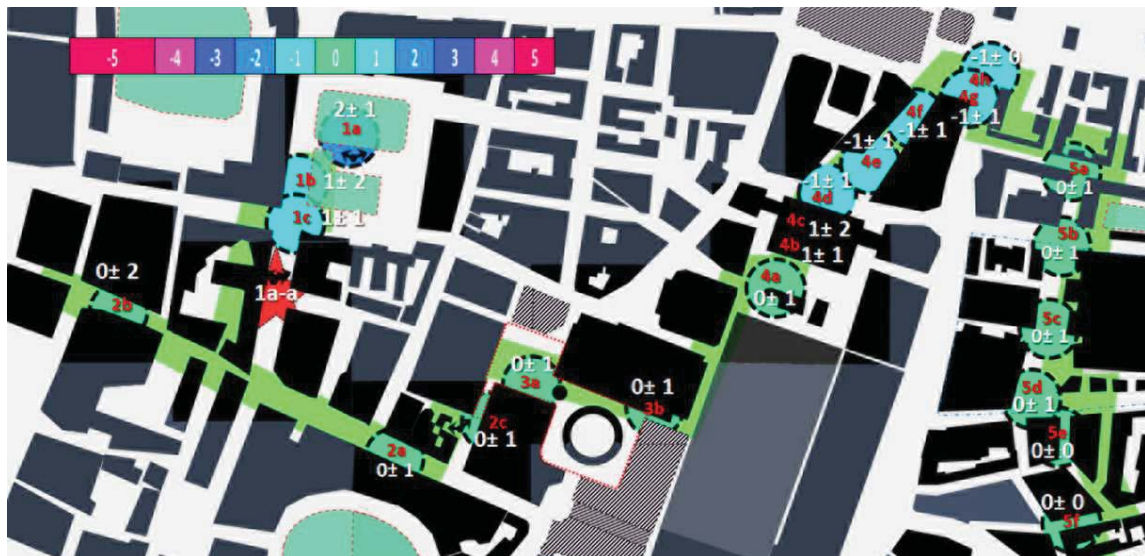


Figure 6. Average air temperature differences for stops  $\emptyset 1a/b/c - \emptyset 2a/b/c - \emptyset 3a/b - \emptyset 4a/b/c/d/e/f/g/h - \emptyset 5a/b/c/d/e/f$ . here we can see that during this winter period air temperatures are generally consistent and little variation exists despite variations in wind speed. As to figure 3 the variations in colour represent the range of readings

This small increase is considered to result from the received reflected radiation from the large south facing building surface located on the north edge of Finsbury square. Nocturnal air temperature readings are expected to show a much wider range of microclimate effects on top of London's nocturnal urban heat island.

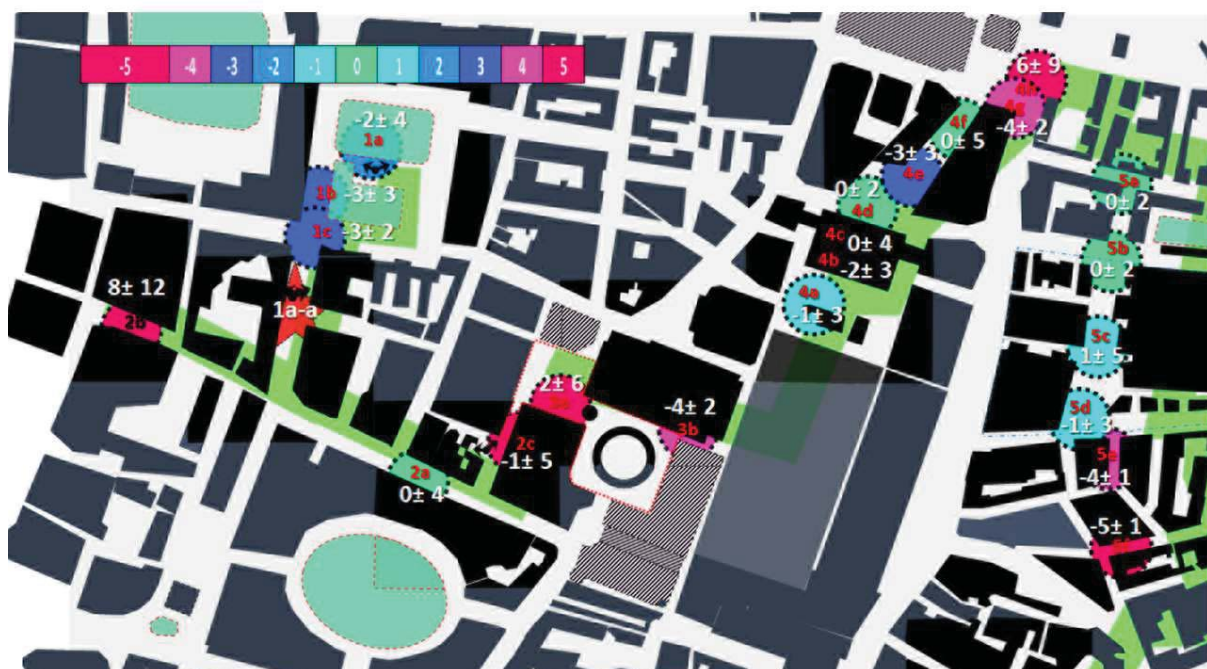


Figure 7. Max wind speed (mph) for  $\emptyset 1a/b/c - \emptyset 2a/b/c - \emptyset 3a/b - \emptyset 4a/b/c/d/e/f/g/h - \emptyset 5a/b/c/d/e/f$ . here we see that wind speeds show a wide variation as a result of the variation in built form. As to figure 3 the variations in colour represent the range of readings

In recent times glare was also be highlighted as significant microclimate issue when the concave south façade of 20 Fenchurch Street modified its surrounding by focusing and concentrating the afternoon September sun into the adjacent streets (Eastcheap) raising surfaces temperatures to a reported 100 °C. The solution was to add a brise soleil to the

offending surface, however as shown in figure 8, whilst this may have lowered the impact on neighbouring streets the built form effect can still appear. The image in figure 6 clearly shows a double shadow, each as focused as the other, making it difficult to determine which is from the sun and which is from the redirected solar beam.



Figure 8. 20 Fenchurch Street. Left) reflection of the surface of the south facing façade resulting in a double shadow despite the post construction addition of the brise soleil to defuse glare of the concave surface photo taken August 2016. Middle) looking towards the South Façade. Right) schematic showing angle and focus of solar beam for early September.

### *Conclusions and further work*

Here we can draw some general conclusions; the small range in air temperature differences result from a general mixing of the air in the street canyons; but that reflectivity may play a role towards increasing thermal comfort; that the winter conditions have a role to play in lowering thermal inertia; there was no obvious examples that suggest anthropogenic emissions are rising air temperatures. That the worse wind conditions were found at the base of tall buildings, particularly on the windward side at the base of tall buildings that result from deflection of the unobstructed wind; however, the venturi effect can disturb the leeward side; that gustiness plays a significant role in distorting form driven wind effects, whereby one side of a building can exhibit both higher maximum speeds but lower average wind speeds than another; and finally, that the chill factor is a significant but overlooked parameter in thermal control.

Overall this preliminary research has highlighted some of the important aspects of built form driven energy effects, and highlight the need to gather evidence for the role of urban setting in modifying background climate conditions and to establish the sensitivity of urban 'form' parameters on energy driven outcomes, including thermal control. The next steps are to investigate these site-specific outcomes over a range of background climate and weather conditions. Finally, open spaces are also interesting, as whilst the results here demonstrate that they generate both sheltered and hostile environment. These outcomes need particular attention when considering a residential function.

These early results demonstrate that the various built form configurations found in the City of London offer a prime location to better understand the significance of built form energy outcomes.

## References

- Bohnenstengel, S. I., Evans, S., Clark P. A. and Belcher S. E. 2011 Simulations of the London urban heat island Q. J. R. Meteorol. Soc. 137: 1625–1640,
- Breheny M, (ed.). 1992. Sustainable Development and Urban Form. London: Pion
- CIBSE 2015 Walking Among Giants - <https://www.cibsejournal.com/uncategorized/walking-among-giants/>
- Emmanuel, R. (1993). A hypothetical 'shadow umbrella' for thermal comfort enhancement in the equatorial tropical urban outdoors. *Architectural Science Review*, 36, 173–184.
- Emu-analytics Building Heights in England on-line resource (2016) <http://buildingheights.emu-analytics.net/?x=-0.08313283924897519&y=51.5107632990935&z=15.103224868250733>
- Fletcher, J., Mills, G., Emmanuel, R., Korolija, I. (2017) Creating sustainable cities one building at a time: Towards an integrated urban design framework *Cities* 66 63–71
- Fletcher, J., Kershaw, T., & Mills, G. (2013). Urban form and function as building performance parameters. *Building and Environment*, 62, 112–123.
- Olgay, V. (1963). *Design with Climate: Bioclimatic Approach to Architectural Regionalism*. Princeton University Press
- Givoni, B. (1998). *Climate Considerations in Building and Urban Design*. New York: Wiley.
- Jabareen Y. 2006. Sustainable urban forms: Their typologies, models, and concepts. *Journal of Planning Education and Research*, 26, pp. 38-52
- Knowles, R. L. (1981). *Sun Rhythm Form*. 1981. Cambridge, MA: MIT Press
- Ratti, C., Baker, N., & Steemers, K. (2005). Energy consumption and urban texture. *Energy and Buildings*, 37, 762–776.
- Ratti, C., Raydan, D., & Steemers, K. (2003). Building form and environmental performance: Archetypes, analysis and an arid climate. *Energy and Buildings*, 35, 49–59.
- Steemers, K., Raydan, D., Ratti, C., & Robinson, C. D. (2000). PRECis: Assessing the Potential for Renewable Energy in Cities. Final Report, Cambridge
- Martilli, A. (2014). An idealized study of city structure, urban climate, energy consumption, and air quality. *Urban Climate*, 10, 430–446.
- Watkins R, Palmer J and Kolokotroni M (2007) 'Increased temperature and intensification of the urban heat island: implications for human comfort and urban design' *Built Environment* 33(1)

# Levels of Biophilia in Architecture – A Survey in Contemporary Izmir

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**Abstract:** Biophilia is the instinctive fondness for forms of life -flora, fauna, or both. It has been embedded in personal and social life for many centuries, since domestic animals and agriculture became parts of human activities. It has also been reflected in architecture, with the Hanging Gardens of Babylon being a legendary example from antiquity. In our times, the relation of built space with vegetation has been drawing a growing attention, especially in the so-called “green architecture”, materialized in various formats and at various levels of attentiveness.

This study originates from the observation that there are diverse ways to express one’s own biophilia; e.g. from hanging a deer’s head on the wall, to demonstrate for protecting a civic park against developers. Similarly, in architecture there are different ways to merge the flora version of biophilia with buildings, according to the priorities of the building industry ‘triangle’: designers, developers, users.

A survey of contemporary examples from the Turkish city of Izmir illustrates various approaches to biophilia in the local architecture, ranging from symbolic to genuine, from minimal to overwhelming. The aim is to discover the inner motivations of those behind such applications, and in general to appraise the current role of biophilia in shaping the urban environment in Turkey.

**Keywords:** biophilia, Turkish architecture, Turkish biophilia, sustainability, Izmir

## Introduction to Biophilia

The word biophilia means ‘love of life’, referring to the human need for contact with nature and living species, both flora and fauna. The word ‘biophilia’ was first used by Erich Fromm (1973), who described biophilia as “the passionate love of life and of all that is alive.” The term was later used by biologist Edward O. Wilson (1984), who suggested that the inclination of humans to focus on and to affiliate with other life-forms has a genetic basis.

This paper focuses on the relation between living organisms and built environment (architecture) in Turkey. Wilson (1986) deliberated that biophilia is not only an aesthetic preference but also a major necessity for people, similar to the need for water, food and air.

The name of biophilia is new but the concept is not. According to researches, in ancient Greece, hospitals and educational fields were set in natural surroundings. Similarly, in Ottoman architecture, mosques, palaces and other major buildings included gardens and green elements to support social and mental balance.

Accumulated evidence shows that contemporary people generally spend their 90% of time inside buildings. Green buildings respond to the need for spaces where human live in relation with natural features. The effects of having green elements in our built environment include a contribution to our mental health in a positive way and also an improvement of building performance such as in humidity control and improving heating and cooling conditions.

Samuel and Sarah (2009) explain that biophilia is related with passion of nature. The human disposition is about turning back to nature. We feel good in nature. In addition of that, our physical and mental well-being depends on the natural environment. Biophilic design struggles the negative effects of urban zone heat and improves the human physical and mental comfort to create a healthy human life. It has abilities which to reduce stress, to



aid recovery from illnesses and to raise academic performances. Ansbacher (2000) adds: "It affects our personal well-being, productivity and even relationships with others."

Kellert (2005) argues that the idea of 'biophilia' is related with an understanding of human evolution, where for more than 99% of our species history we biologically developed in an adaptive response to natural not artificial or human created forces. Researches show that human body and spirit want to be in contact with nature. The human body, mind, and senses evolved in a bio-centric not human engineered or invented world.

In addition to such ideas, Locklear (2012) states that from past to now, humans use many natural resources in their life and in their spaces. Using concepts of biophilic design to guide the decisions for the built environment, spaces are designed to support healing through biophilic responses and connections to natural elements and systems. In the present times, we have bigger spaces but their materials do not promote our positive psychology and well-being physical conditions. To overcome that, our living spaces and built environments should be integrated with nature.

### **Biophilic Design in Architecture**

Referring to the benefits of biophilic design, Almusaed (2011) states that biophilic design assists us to optimize comfort and reduce natural resources depletion. The main benefit of this design ideology is designing new buildings and interiors with economical, social and ecological considerations. The concept is include durable materials for providing consumption and creation of healthy elements. Green design concepts can improve both, the building functions and human health through natural energy sources, fresh air, proximity to nature, releasing from the stresses of the city.

Authors believe that biophilic design includes two main elements; organic design and vernacular design which is place-based design. Organic design is concerned about usage of shapes, forms and materials in buildings and landscapes in relation with nature, directly or indirectly. This design type promotes the use of natural lighting, water, ventilation and also the use of healthy, natural materials.

Vernacular design refers to buildings or interior spaces that design in connection of culture, history and ecology with geographical aspects. Related with these aspects, we can clearly say that the use of natural lighting, natural ventilation, natural materials and natural forms are common expressions of organic architecture and biophilic design. These features can be the result of design decisions for basic and advanced level of biophilia.

Biophilic concepts extend beyond the walls of buildings and can include site planning, community and land use planning issues as well. After decades with numerous negative urban renewal examples, society is shifting back to wanting a balance between urban living and natural surroundings.

According to Beatley (2011) the biophilic cities are leaders in this respect, showing what it takes to promote urban sustainability. If people become conscious about the ways nature solves all problems in her own way, then our interiors, our buildings and our public spaces would be more utilitarian and sustainable.

Nature directs the city, shaping the relation between buildings and air, earth, water and other living organisms. Cities should become the most environmentally-friendly model for inhabiting our earth. It is more important than ever to re-conceptualize existing cities and their systems of infrastructure, to be compact, mixed-use and polycentric cities.

Concept of biophilic city is all related with that ideas. Humanity should start the changing from micro to macro spaces.

### Types of Contemporary Biophilia in Turkey

Given the rapidly increasing population in Turkey, urban planners and architects strive to protect nature and wildlife through landscaped gardens and nature reserves. They also promote residential zones community gardens, and also install green roofs and living walls.

The importance of greenery in buildings is pointed out by Söğüt & Şenol (2004): *“Based on World Bank statistics, 73% of Turkish population live in cities. This high percentage has negatively affected life quality with degraded urban fabric, and it has unbalanced structural elements and green areas.”*

Green roofs and façades are proven to be effective in enhancing the quality of life. In cities with green zones, the urban heat island effect can be lowered, and reduced relative humidity can be increased. Eliminating the differences between urban living spaces and rural areas can increase living quality. Green roofs and façades also offer significant benefits by capturing dust and other aerosols in the urban atmosphere. By holding a certain amount of rain water, storm water runoff can be decreased. Studies revealed that traffic noise in cities is reduced with the soil and plant cover of green roofs.

In Turkey, climate change affects some important matters nowadays. Studies have shown that urban heat is growing in urban areas in the western regions of Turkey. In response to such effects, cities like İstanbul and İzmir have developed extensive stimulations for installation of green features, such as green rooftops and green walls (Figure 1, Figure 2).



Figure 1. Green rooftop of Zorlu Center / İstanbul.



Figure 2. Green walls of Point Bornova Shopping Mall / İzmir.

### Examples

#### ***Greenery on the Ground Level: AGORA Shopping Mall – İzmir***

A 90,000 square meter rectangle mall forms the heart of the project and is complemented by a series of shared green spaces, including parking areas. The word ‘Agora’ in ancient Greek was used for ‘open place of assembly’. Later the Agora defined the open-air, often covered by canopies, marketplace of a city where merchants had their shops and where craftsmen made and sold their wares. According to this concept, the complex has different atrium and public spaces with greenery added in various parts of the mall, indoors and

outdoors. The aim is to improve the lifestyles of urban people with special focus on the environmental impact of human activities (Figure 3, Figure 4).



Figure 3. Building surrounding of Agora Shopping Mall / İzmir



Figure 4. Atrium of AGORA Shopping Mall / İzmir

At Agora Shopping Mall, designers favoured a light, natural colour palette and more natural light for the common spaces in the mall three main sections. This is a clear indication of their view that green spaces can increase the physical and psychological wellbeing of visitors and workers of the mall.

The designers installed many banana trees in the public courts, blending them with seating areas around the ornamental pool that were accented with shades of green and blue to add additional naturalism to the area. The theme of naturalism is carried throughout the shopping mall, with containers planted with small trees, perennial flowers and ivies to add the right amount of organic feel to the fairly contemporary design. Plants are also known to reduce noise levels of interiors which is important for large shopping malls that can become quite noisy when crowded. Customers complains about noise can be prevented by adding more foliage into the design.

Commercial environments profit by nature's inherent powers to put people at ease by design interiors, exteriors or public spaces with lush greenery. Many studies have shown that the rich presence of indoor plants can improve human well-being and increase human energy level. In Agora shopping mall, from indicating walking routes to providing shoppers



with relaxing places to rest during shopping, plants have been used in various ways in the entire shopping centre area.

### ***Greenery on the Facades: Balconies in İzmir***

Even though the amount of green spaces has increased after the studies carried out by İzmir Metropolitan Municipality and Regional Directorate of Forestry, the green development has been focused on the countryside outside the city centre, mainly on the forests surrounding İzmir. But increasing the built areas against the green areas of the city affects negatively the quality of life. According to the development plan Turkish law No. 3194, the targeted green area ratio, which is determined as 10 square meters per person, is seen as a difficult target to reach under the present conditions of the country. Based on the knowledge given by the İzmir municipality, it is determined that the amount of green space per capita is 12.68 square meters in 2015 in İzmir. (Figure 5)



Figure 5. Centre of İzmir

Although the space is usually limited, generally balconies in İzmir allow people to do some gardening. Residents use frequently their balconies as front gardens but in lesser scale, regardless of their balcony size. This can be related both to İzmir's climate and to the needs of people for contact with green elements (Figure 6).



Figure 6. Beautiful Balcony in İzmir - Anonymous

To protect and improve the built and natural environment, İzmir local boroughs promote the addition of green on balconies and gardens. For example, Bornova Municipality and Karşıyaka Municipality organize 'Beautiful Balcony - Beautiful Garden Contest' in order to raise awareness about environmental issues, to improve living environment in the city by increasing greenery and to create high quality urban spaces. These competitions affect people in terms of environmental sensitivity. Thanks to these competitions, environmental awareness is increasing, and cities are encouraged to create more liveable and green spaces (Figure 7).



Figure 7. Beautiful Balcony in İzmir - Anonymous

### **A green survey in İzmir**

This research involves a survey on the use of green space and the need for green areas by people in İzmir, and also evaluating existing green spaces according to user needs.

The quality aspect of green spaces is as big as their spatial importance. The value of green spaces in the built environment is increasing due to the positive effects on human body and spirit as well as on microclimate, air conditioning, dust filtering and noise reduction.

Most of the general population is not directly aware of all the above, yet the public can feel the effects of such subjects on their everyday lives. That kind of public awareness is a topic that the present work aimed to explore through a public survey using questionnaires. That survey was combined by an additional one in the form of interviews of a couple of designers.

### ***Views on biophilia by the public***

The objective of the public questionnaire was;

- To analyse interaction of local people with nature in the context of architecture
- To assess how greenery in built environment affects local people.

The questionnaire was divided in 3 parts;

- Personal preferences of participants,
- Use of greenery in their life and how,
- Interaction with greenery in their built environment.

The survey results showed that the difference in social and economic class directly affects the forms of usage of biophilic elements and sensitivity to green space. It appeared that the level of education and the area they live in affects the way people view nature. People living in a residential unit with a high level of education differ in their disposition versus greenery than most of the working people with a rural social origin and a low education level.

When the data on the adequacy of the existing green areas defining the "quality of use" according to the users are taken into consideration, it is seen that the negative results of the outcomes are largely suppressed. When it is asked to the local people that enough green areas in the cities and regions they live in, it is found that green areas are not enough by a high rate of 92%. When the question of how they feel in the green areas is asked to the participants, the answers are quite positive. 83% of the participants pointed that they felt peaceful in green areas. All participants stated that green areas have an important contribution to the creation of urban identity and image of the city and urban places, and that green areas add wealth to cities and buildings in terms of plant diversity and natural landscape values. (see Fig.8 and Fig.9)

80% of the people think that the urban transformation projects reduce the existing green area ratio and the municipalities should support the increase of the green space at the urban environment.

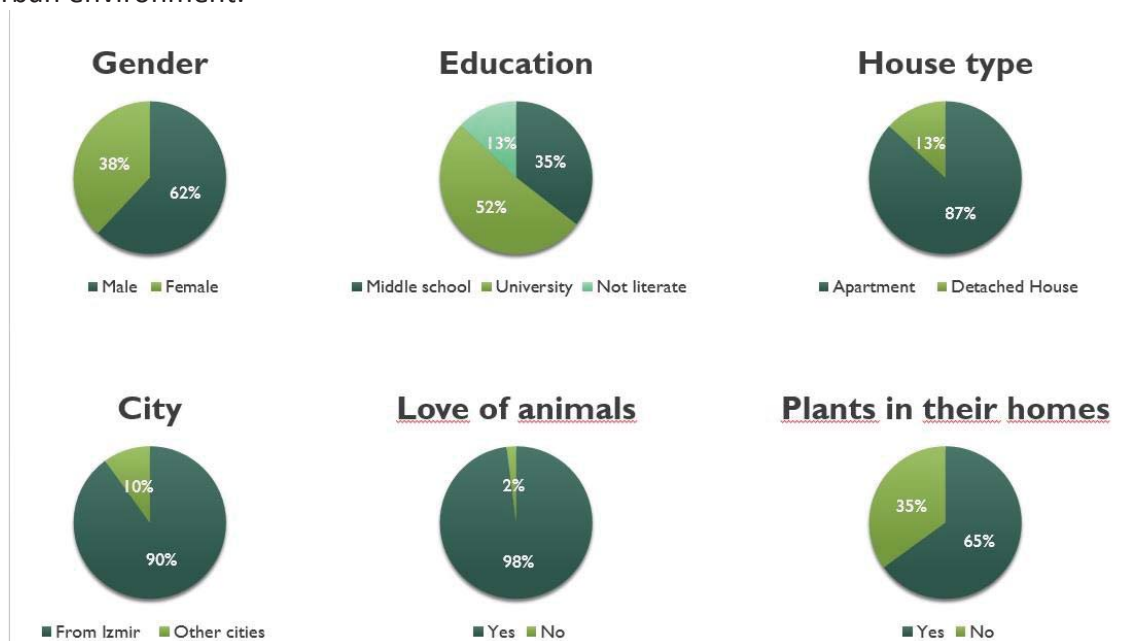


Figure 8. Results of questionnaire which made in İzmir. 2017



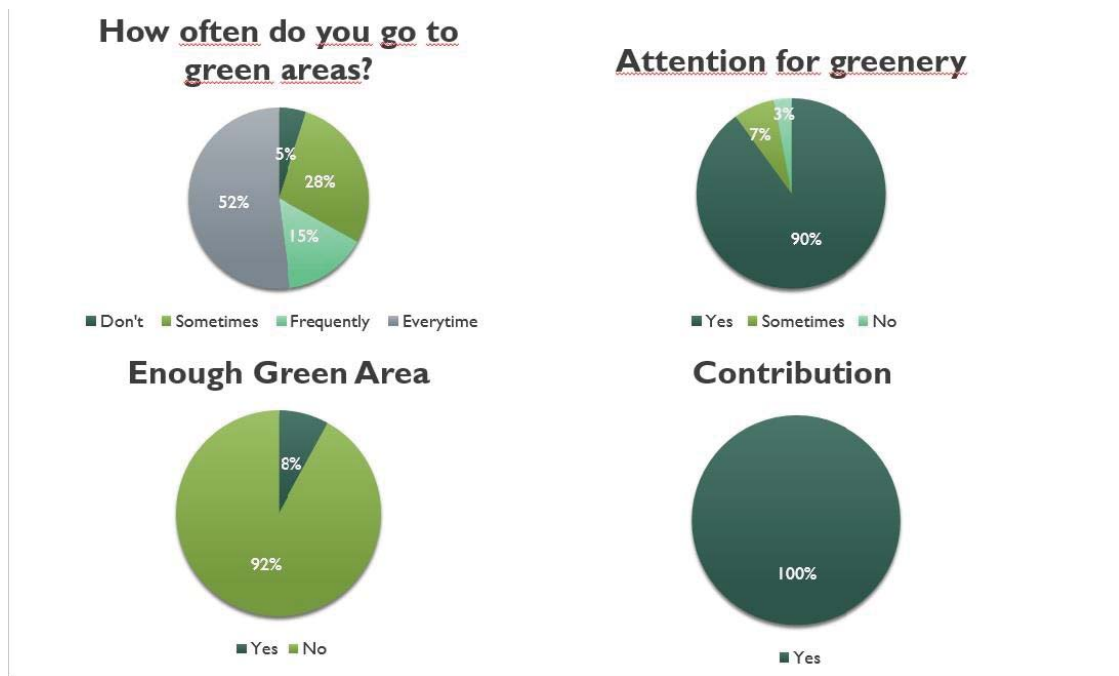


Figure 9. Results of questionnaire which made in İzmir. 2017

According to the survey in İzmir, the city provide a modern and green city view to the people and to meet the open-green area needs of present and future people. First of all, applications to develop green plans made by the municipality and these should be planned and designed rationally, aesthetically and functionally according to the conditions of the ecological, social, economic and cultural features of the city. When implementing city development plans, sociological and human health oriented considerations should always be kept on the front line, rather than political aims and tendency to create land rents.

### ***Views on biophilia by designers***

Designers and the community agree that natural resources are being used wildly in the world, mainly due to industrialization, rapid population growth and parallel urbanization. Not only air pollution creates great risk for built environment, and also water pollution and destruction of agricultural lands are big deal for city and local people. For years, natural resources such as soil, water and air have been perceived as cheap and available resources for industrial production. We can consider the idea of green architecture as a reaction to the fast depletion of nature in this sense, as a form of protest or opposition. Again, the term "sustainable", which is used to describe almost every concept in recent times, is indeed a sign of how the difficult situation is.

### ***Interview with designers- Erbil Coşkuner***

An interview was made with Erbil Coşkuner, the architect of the Agora shopping centre, about green spaces, which have become a new trend in the design world as well as an important necessity. In the interview, the use of green spaces in İzmir and the implementation of green elements in Turkish modern architecture were discussed.

Summarizing Erbil Coşkuner's ideas about greenery, he pointed that sustainability has become a necessity, not a voluntary choice. Design and sustainability principles must be

combined to address the effects of climate change, and architectural education must evolve. It is envisaged that in the coming years, green building criteria will be included in the standards and that everyone who has or does not care about sustainability will have to know this. The architectural field as in the world, technological developments in Turkey are increasing. But simultaneously with these technological developments, damage to nature has increased and climate change has become a current issue. The destruction created is above the nature's self-renewal capacity. Unconscious consumption has caused us to recognize our limit on resources. Finally, and most importantly, human health is at risk.

### ***Interview with designers- Dürrin Süer / Metin Kılıç***

İzmir hosts some interesting projects related to biophilia. One of them is Asma Bahçeler (see Fig.12), so an interview was made with Dürrin Süer and Metin Kılıç, two of its architects, about biophilia and how nature interacts with architecture. The architects stated that they did not start with the creating fake concepts for existing structure. They go through the idea of how we can integrate into the existing nature. It is important that the ventilation, illumination and view of the building are perceived from the interior. They emphasized that their basic tendency is the continuity and fluidity of the inner-outer association. They are trying to use the natural resources to consume the current energy such as sunlight and wind.

First of all, users need to live with nature. They are trying to create a more sustainable system, not destroy nature. Architects emphasized that the city have become more disconnected from nature. Nowadays, they concentrate on green roofs in designs. And also they try to integrate nature into the spaces without using green elements such as implemented in Japanese philosophy. Architects stated that the most important point of their designs is to integrate nature with minimum intervention.

### **Discussion**

Based on the observed applications, authors believe that there are two type of biophilia; basic and advanced.

Basic is greenery with a rather decorative function – e.g. flower pots on a balcony.

Advanced is greenery incorporated in the built environment in an effective manner – e.g. green roofs.

In Turkey, we see examples of both types, especially many with a ‘vernacular’ character that reflects an instinctive, grass-roots biophilia.

Two projects in İzmir city exemplify these two categories, Folkart Narlidere (10, Figure 11) and Asma Bahçeler (Figure 12, Figure 13).

If a design does not focus on aspects of the natural world that contribute to human well-being in the age-old blending with the natural world then it is not biophilic. When we analyse the Folkart Narlidere example, there are some potentially biophilic features such as sea view, green elements etc. In the Folkart Narlidere complex, the topography of the area in which the land is located, the existing structural patterns, the urban features such as transportation and density, and the sociological structure of the area were analysed. Structural concept and elements created for future users in the light of human needs. The natural texture, which is concentrated both vertically and horizontally over the usual dimensions, has been predominantly the main material of the filters and has been transformed into an integral part of the structures in this context.

On the other hand, at the beginning of the project, the designer selected to use olive trees on the facades. The main building is behind a large scale steel lattice holding many small olive trees. According to Salingaros (2015) there are many factors that contribute to human wellbeing is biophilia, our attraction to the geometry of biological structures. This very broadly includes enjoying environments that are either natural, or that mimic nature in an essential geometrical manner, but not just as a superficial copy or decoration. Biophilia also includes our positive interaction with other persons, which is necessary for us to live life fully. In the light of these positions, Folkart Narlıdere can be interpreted as a pretentious approach to biophilia. The concept appears to be just adding some green elements and use them as a selling advantage. If green elements want to serve a genuine biophilic idea, they should serve functions like shading or cooling, not just symbolic decoration.



Figure 10. Potted plants for shading elements- Folkart Narlıdere Residence, İzmir. Architect: Emre Arolat.



Figure 11. Potted plants in balconies- Folkart Narlıdere Residence, İzmir. Architect: Emre Arolat.

Another interesting example is Asma Bahçeler. An upmarket apartment complex of over 100 apartments on a green slope of Narlıdere, not too far from the previous example. It demonstrates the use of biophilia as a property selling advantage as in Folkart Narlıdere. Departing from the green tower paradigms, the multi-storey building has a stepped up layout following the natural slope in an area with more trees than building. The green roof of one storey is the garden of the next above. Asma Bahçeler can be considered as a successful project in terms of adaptation to the land and offers a life close to nature for all its inhabitants. The project has characteristics that do not disturb the texture of the

mountain and the city as other constructions do. This is very important for İzmir, which is developed frequently on rugged land.



Figure 12. Asma Bahçeler Residence, İzmir. Architects: Tanyer İnşaat.



Figure 13. Asma Bahçeler Residence, İzmir. Architects: Tanyer İnşaat.

## Conclusion

This paper focuses on the use of vegetation in the built environment (architecture) in İzmir. The work considers some types of greenery, which are green landscape, green roofs and living walls as manifestations of biophilia in the Turkish urban context, representing an interaction between people and nature. Starting from various examples, the study explores the main social facts about biophilia and how people react to green elements.

A survey showed that the benefits provided by the green areas are well known by the people of İzmir, enabling them to have reasonable demands on these areas. This will help to raise the level of awareness on the essential functions of green spaces in the city and to create more appropriate policies to be formulated through the participatory approach. By protecting the existing green areas in Turkey, the amount of green space per capita can be increased and green areas can be organized for the benefit of citizens. These spaces also have an educative role on society and an ecological meaning for the city. The ability of green

spaces to create environments for all kinds of cultural activities will allow sharing of various information and communication with different cultures and will have an impact on community education.

The majority of people feel relaxed and happy in a biophilic setting, and they want to see more green elements in their built environment. According to the results of the surveys, the benefits provided by the green areas are well known to the people. The addition of a variety of plants and natural setups in the city of İzmir -and similarly to other urban centres- will satisfy people's demands. This will also help to increase awareness of the importance of green spaces and to create more concise policies formulated through a participatory approach.

Some designers are motivated by biophilia or sustainability. In practice many architects understand that green spaces are more user-friendly. Developers also realize that buildings with biophilic elements are more marketable.

In İzmir, there are signs that biophilic ideas have been put into practice. The local authority follows the desires of the people to provide a modern and green city and meet the outdoor green area needs of present and future generations.

It is important to realize that biophilia in the spatial design field is more than just a new way to make people more satisfied by applying an innovative technical tool. The successful application of biophilia in architecture fundamentally depends on adopting a new consciousness toward nature, recognizing how much our physical and mental wellbeing continues to rely on the quality of our connections to the natural world around us of which we still remain a part.

## References

- Almusaed, Amjad. 2011. "Biophilic and Bioclimatic Architecture: Analytical Therapy for the Next Generation of Passive Sustainable Architecture". Springer-Verlag London Limited.
- Ansbacher, Samuel and Sarah. 2000. "What Is Biophilia? And Why You Need Biophilic Design In Your Home".
- Fromm, Erich (1973). *The Anatomy of Human Destructiveness*. Holt, Rinehart and Winston, New York.
- Kellert, Stephen R. 2005. "Building for Life: Designing and Understanding the Human-Nature Connection". Island Press Product.
- Locklear, Kendra Michele. 2012. Guidelines and Considerations for Biophilic Interior Design in Healthcare Environments.
- Salingaros, Nikos A. (2015) "Biophilia and Healing Environments: Healthy Principles For Designing the Built World". New York: Terrapin Bright Green, LLC.
- Söğüt, Z. & Şenol, D. 2014. "Kentsel Çevre Kapsamında Yeşil Çatı ve Cephelerin Değerlendirilmesi". ISEM 2014: 733-742.
- Wilson, O. Edward. (1986). Biophilia.
- Beatley, T. (2011). Biophilic Urbanism: Global Methods and Metrics (1st ed.). [http://biophiliccities.org/wp-content/uploads/2012/04/SummitFoundation\\_BiophilicUrbanismProposal\\_November20111.pdf](http://biophiliccities.org/wp-content/uploads/2012/04/SummitFoundation_BiophilicUrbanismProposal_November20111.pdf)



# Daylight Assessment of an Integrated Shading System for Typical Office Spaces

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**Abstract:** The issue of environmental renovation of aged existing building stock for the improvement of indoor environmental conditions forms a field of high interest and extensive research. The present research aims to evaluate the integration of a movable louver shading system for the improvement of visual comfort of existing office buildings. The system was evaluated by means of daylighting analysis simulation using Ecotect 2010 and Desktop Radiance v2.0. Daylighting performance indicators, i.e. daylight factor (DF) and uniformity daylight factor (UDF), were calculated for various geometrical configurations with the louvers rotating both on horizontal and vertical axes. Moreover, an in-depth analysis of lighting levels was performed for selected horizontal configurations for south-facing spaces during different periods of the year and hours of the day. The analysis suggests that the integration of the louver system in appropriate geometrical configurations keeps high percentages of the plan area in sufficient lighting levels, while it significantly minimizes the possibilities of glare issues. The research study confirms the positive contribution of the system under study, as a daylighting regulation system. The parallel analysis of daylighting performance indicators and of lighting level offers a holistic and comprehensive approach to the investigation of the visual comfort conditions of the indoor built environment.

**Keywords:** existing building stock, integrated shading system, daylighting, glare issues, visual comfort

## Introduction

The existence of aged building stock in the European cities is the result of intense building construction during the last century. The majority of these buildings, mainly built during the postwar reconstruction decade, did not abide by any environmental principles or energy efficiency measurements. Due to the fact that no energy performance criteria or sustainable building policies had been provided, these buildings demonstrated high energy consumption to meet the heating and cooling demands as well as sufficient artificial lighting in indoor spaces. In Europe, the energy consumption of buildings reaches 41% of the total energy consumption, with the office buildings being one of the most intensive energy consumers (Janssen, 2004). The extensive use of glazed surfaces of existing office building envelopes, contributes to their increased energy consumption for cooling and heating (Michael et al, 2016). On the other hand, extensive glazing allows a better visual connection between the indoor and outdoor environment as well as increased natural lighting, reducing the need for energy consumption for artificial lighting (Poirazis et al, 2007).

Currently, the environmental upgrade of aged existing building stock for the improvement of indoor environmental conditions forms a field of high interest and extensive research. The renovation of existing building stock is preferred against demolition and reconstruction due to its limited ecological impact. Moreover, prosthetic renovation ensures the buildings' environmental upgrade without the need for relocation of the occupants during the construction period (Almussaed et al, 2014). The buildings' façades compose a filter for external climatic parameters, e.g. solar radiation, daylight, wind, etc.,

providing a desired level of regulation of the environment conditions (Selkowitz et al, 2004). In this framework, the design of the building façade, as well as the construction techniques and material selection have a significant influence on the indoor comfort of occupants as well as on the building's energy consumption (Hammad, 2010).

In this context, the current research deals with the environmental renovation of the existing building stock. More specifically, an environmental prosthetic renovation approach, based on an integrated movable louver system for daylighting regulation, is proposed. The integration of the louver system in appropriate geometrical configurations offers sufficient lighting levels in a high percentage of the plan area and minimizes the possibilities of glare issues providing at the same time, better visual conditions in the indoor environment. Moreover, daylighting regulation is directly related to energy saving, since it contributes to the reduction of energy consumption caused by the use of artificial lighting.

## Literature Review

According to the International Energy Agency (IEA), artificial lighting is responsible for 14% of electricity consumption in the European Union (International Energy Agency, 2009). Moreover, many researches note that visual and thermal comfort in office spaces ensure significant benefits to the employees in terms of both physiological and psychological aspects. Sufficient lighting levels have an impact on health and wellbeing; they contribute to better work performance, i.e. minimization of working errors and absenteeism (Athienitis et al, 2002; Tzempelikos et al, 2006; Michael et al., 2017a).

It is generally recognized that the most efficient way to reduce direct solar gain in buildings is to block the solar radiation from entering the indoor space (Radhi et al, 2009). This can be achieved through the use of solar control systems which can be either glazing materials, i.e. prismatic glazing, holographic optical elements or mirrors, or shading solar systems, i.e. architectural elements, louvers and blinds. (Palmero-Marrero et al, 2009).

Louvers and blinds are systems designed to capture the sunlight entering the front part of a space and lead to substantial energy savings (Hammad, 2010). Moreover, depending on their geometry and properties of materials, they have the ability to redirect sunlight towards the back of the space improving the lighting distribution of the interior (Nielsen et al, 2011). In this framework, a significant number of studies have been pursued, investigating different shading systems for optimum visual and thermal performance.

Internal shading devices can be more appropriate and efficient options to reduce discomfort glare by blocking direct sun and excessive lighting levels, while allowing direct solar gains which are desirable during the heating period (Grynning et al, 2014). The investigation of different external solar shading systems and their impact on the total energy demands of a typical space, i.e. heating, cooling and artificial lighting, was performed in a typical office spaces in Denmark in different orientations. The study showed that the integration of suitable shading systems led to significant energy reduction. At the same time, it showed that dynamic solar shading systems ensure improved daylight performance compared to fixed solar shading systems (Nielsen et al, 2011).

Moreover, a lightweight plug-in movable envelope has been recently investigated assessing the possibilities of the system for the optimisation of visual comfort in the existing building stock in southern Europe. The research findings confirm the positive contribution of the proposed system, while at the same time the study establishes the concept of prosthetic renovation as a renewable energy strategy for the improvement of indoor comfort of existing buildings (Michael et al, 2017b). Finally, a large number of recent research studies

have focused on the investigation of the architectural integration of solar energy systems in the envelope of existing buildings, highlighting their role as passive and active solar systems (Bougiatioti et al, 2015).

Although the issue of environmental renovation of aged existing building stock for the improvement of indoor human comfort consist a research field of high interest, the existing literature in the field of environmental sustainable façade design remains rather limited. Moreover, the majority of relevant existing studies focus on the building's energy efficiency rather than on daylighting performance of the indoor built environment. Taking the above into account, the present research aims to evaluate the integration of a movable louver shading system for the improvement of visual comfort of existing office buildings. The system is quantitatively evaluated, using software simulation analysis, aiming to provide better indoor visual conditions.

## Research Methodology

### *Case study description*

Within this framework, a typical office space was selected for detailed investigation. For the selection of the most representative case study, an investigation of the typologies of existing office building stock constructed in Europe during the last decades of the previous century was performed. Based on this study, the typical floor plan consists of a central linear corridor which gives access to office spaces on both sides. The typical office spaces are usually of rectangular shape and are placed in a vertical arrangement in relation to the corridor. This plan layout, allows for openings along the external short side of the space. It is also noted that typical office spaces appear in all four orientations.

The office space under study has typical plan dimensions 3.50 x 5.50 x 2.75m (W x L x H), while the external façade accommodates a glazed opening with dimensions of 3.10 x 1.75m (W x H), located 1.00m above the finish floor level. The walls are made of clay bricks with plaster finish, while the exterior walls are thermal insulated with appropriate insulation materials. The upper concrete slab is covered by a false ceiling made of gypsum boards, while the lower concrete slab is covered by a typical suspended floor covered by timber tiles. The opening consists of aluminum window frames and double glazing (Figure 1).

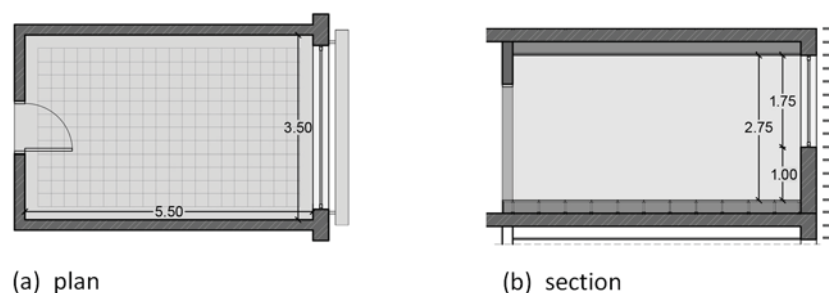


Figure 1. (a) Plan layout and (b) section of a typical office space along with the integrated shading system at a horizontal configuration.

### *Shading System*

The proposed movable shading system is located parallel to the building's façade at a distance of 0.25m and integrated therein using lightweight metal frame. The movable louvers have 0.25m width and are placed at a distance of 0.25m from each other. The louvers are made of aluminum with rather high reflectivity properties allowing thus, the reflection of sunlight. The louver slats of the system rotate in all possible angles from 0° to

180° and can be installed on vertical or horizontal axes. The flexibility of the system allows the appropriated configuration for optimum daylighting performance depending on the façade orientation, the period of the year and the hour of the day.

### ***Daylighting Analysis Simulation***

For the evaluation of daylighting performance of typical office space in existing building stock, Autodesk Ecotect Analysis 2010 and Desktop Radiance v2.0 were selected for daylighting analysis simulation. Autodesk Ecotect was used as a modelling and visualization tool, while Desktop Radiance was used for the daylight analysis. The simulation of daylighting is performed for Larnaca, Cyprus (latitude 35°10' N and longitude 33°50' E).

The reflectivities of the model's surfaces were selected according to the typical indoor and outdoor materials of office spaces, based on the IESNA Lighting Handbook (IESNA, 2000). Specifically, the reflectivity of interior walls was set at 0.60, of exterior wall at 0.60, of floor at 0.65 and of ceiling at 0.70. The transmittance of glazing was set at 0.75. The road surface reflectivity was set at 0.05. The reflectivity value of the system's louver slats was set at 0.80; a value which was assessed to be the most appropriate for the present study, after relevant investigation.

Daylighting simulations were conducted at 9.00h, 12.00h, 15.00h (local time GMT+2) under the prevailing sky conditions of each period under study, i.e. mostly clear sky (2/8) during the summer solstice, i.e. 21<sup>st</sup> June, and intermediate sky (4/8) during the winter solstice, i.e. 21<sup>st</sup> December, and the equinoxes, i.e. 21<sup>st</sup> March/September. The calculations were made using three indirect reflections, employing an analysis grid of 12 x 20 cells with dimensions 0.25 m x 0.25 m. The analysis was performed at 0.75 m height from the finished floor level, i.e. the level of working surface. Lighting levels are presented using contours per 300 lux (from 0 to 3000 lux) with analysis accuracy of 1 lux.

### ***Assessment Factors of Visual Comfort***

For the evaluation of visual comfort of the integrated shading system under various geometrical configurations, internationally recognised evaluation criteria of indoor visual comfort were used.

More specifically, the daylight factor (DF), a widely used static indicator of daylight performance was used. DF defines the ratio of interior illuminance on a horizontal surface to the exterior illuminance on a horizontal surface under an overcast CIE sky. According to CIBSE Guide A, the DF should be at least 2% for 75% of the plan area. The preferable daylighting conditions are also defined by the uniformity daylight factor (UDF), expressing the degree of homogeneity in lighting distribution. UDF value is defined by the singular minimum DF value divided by the average DF value of the entire plan, i.e.  $UDF = DF_{min} / DF_{average}$ . According to the assessment method for sustainable buildings BREEAM 2.08, the required UDF for achieving an efficient working environment should be at least 0.40. Moreover, lighting levels, i.e. minimum, maximum and average lux levels, as well as percentages of the plan area exceeding the daylight levels of 300 lux, 500 lux, 2000 lux and 3000 lux, were calculated for selected cases. According to the IESNA and CIBSE Guide A, moderately easy visual tasks can be undertaken at 300 lux, while a level of 500 lux is required for high accuracy human activities. The lighting level of 500 lux in a minimum of 75% of the plan area was set as a limit for acceptable lighting levels. At the same time, the minimum percentage of the plan area with lighting levels exceeding 3000 lux is sought, aiming at the minimization of glare issues.

## Results

The contribution of the proposed system to the improvement of indoor visual comfort of office spaces is presented in this section and discussed on a comparative basis. The results indicate the daylighting performance of the existing office spaces under study for different geometrical configurations derived from the rotation of the shading louvers in both the horizontal and vertical axis.

### *Daylight Factor and Uniformity Daylight Factor Results*

Daylighting performance indicators, i.e. DF and UDF, were calculated in order to evaluate the proposed louver system in different configurations. More specifically, a series of daylighting parameters, i.e. minimum, maximum and average DF, percentages of the plan area exceeding 2% DF, and uniformity daylight factor (UDF) were calculated under overcast conditions.

#### *Horizontal louvers*

In this section the calculations of daylighting performance indicators for different configurations of the proposed system, i.e. rotation angles from 15° to 165° on the horizontal axis, are presented in Table 1. The reference scenario, i.e. space without the integration of any shading system, is also presented for comparative reasons.

Table 1. Daylight factor (DF) and uniformity daylight factor (UDF), calculated under overcast conditions for different geometrical configurations from the rotation of the louvers in the horizontal axis.

Case Scenario	DF (%)			% of space DF >2%	UDF
	min	max	average		
Reference	2.40	17.49	7.20	<b>100.0</b>	0.33
Horizontal - 15°	0.92	9.98	3.07	48.8	0.30
Horizontal - 30°	1.19	12.96	4.46	68.6	0.27
Horizontal - 45°	1.53	11.31	4.91	<b>82.7</b>	0.31
Horizontal - 60°	1.78	9.75	4.61	<b>92.7</b>	0.39
Horizontal - 75°	1.74	8.15	3.99	<b>93.5</b>	<b>0.44</b>
Horizontal - 90°	1.87	5.93	3.38	<b>97.7</b>	<b>0.55</b>
Horizontal - 105°	1.13	3.96	2.33	59.2	<b>0.48</b>
Horizontal - 120°	1.25	3.59	2.10	49.4	<b>0.60</b>
Horizontal - 135°	1.17	3.95	2.14	44.0	<b>0.55</b>
Horizontal - 150°	0.97	3.46	1.78	30.5	<b>0.54</b>
Horizontal - 165°	0.93	2.61	1.49	20.4	<b>0.62</b>

In the reference scenario, the percentage of the plan exceeding 2% DF is 100%, while the UDF value is 0.33, failing to reach the threshold of 0.40. The application of a horizontal louver system with rotation angles from 15° to 30° and from 105° to 165° significantly decreases the percentage of the plan area exceeding 2% DF compared to the reference scenario. However, the integration of the system with rotation angles from 45° to 90° maintains the largest percentage of the plan area (> 75%) with DF being above 2%. Sufficient levels of lighting distribution are observed in the cases of rotation angles from 75° to 165°. More specifically, these particular rotation angles significantly increase the degree of homogeneity in lighting distribution indicating UDF values higher than 0.44 UDF.

The daylighting performance analysis for the different scenarios under study indicates that rotation angles of 75° and 90° on the horizontal axis satisfy the international lighting standards of DF > 2% in a minimum of 75% of the plan areas and UDF > 0.40,



ensuring thus an efficient working environment. More specifically, in the case of the integration of the proposed system with rotation of 75° on the horizontal axis, the lighting level analysis shows 93.5% of the plan area exceeding 2% DF, while at the same time uniformity daylight factor is 0.44 UDF. In the case of the rotation of 90° on the horizontal axis, the lighting level analysis shows 97.7% of the plan area exceeding 2% DF while the uniformity daylight factor is 0.55 UDF.

#### *Vertical louvers*

In continuation of the previous section, this section presents the calculations of daylighting performance indicators for different configurations of the proposed system, i.e. rotation angles from 15° to 165° on the vertical axis (Table 2). The reference scenario, i.e. space without the integration of any shading system, is also presented for comparative reasons.

Table 2. Daylight factor (DF) and uniformity daylight factor (UDF), calculated under overcast conditions for different geometrical configurations derived from the rotation of the louvers on the vertical axis.

Case Scenario	DF (%)			% of space DF >2%	UDF
	min	max	average		
Reference	2.40	17.49	7.20	100.0	0.33
Vertical - 15°	0.68	4.78	1.75	29.3	0.39
Vertical - 30°	1.03	6.84	2.68	48.5	0.38
Vertical - 45°	1.36	9.25	3.62	66.3	0.38
Vertical - 60°	1.35	8.65	3.80	69.1	0.36
Vertical - 75°	1.55	8.94	4.16	<b>83.6</b>	0.37
Vertical - 90°	1.77	9.04	4.43	<b>91.3</b>	<b>0.40</b>
Vertical - 105°	1.62	8.87	4.26	<b>85.5</b>	0.38
Vertical - 120°	1.33	8.70	4.00	<b>75.6</b>	0.33
Vertical - 135°	1.13	8.12	3.35	60.6	0.34
Vertical - 150°	1.15	7.24	2.93	57.8	0.39
Vertical - 165°	0.88	5.01	2.05	38.0	<b>0.43</b>

The application of a vertical louver system with rotation angles from 15° to 60° and from 120° to 165° significantly decreases the percentage of the plan exceeding 2% DF, compared to the reference scenario. However, the integration of the system with rotation angles from 75° to 105° on the vertical maintains the largest percentage of the plan area (> 75%) with DF being above 2%. Moreover, a sufficient level of lighting distribution (UDF > 0.40) is observed in the cases of rotation angles of 90° and 165°.

More specifically, the daylighting performance analysis for the different scenarios under study, indicates that only the rotation angle of 90° on the vertical axis satisfies the international lighting standards of DF > 2% in a minimum of 75% of the plan areas and of UDF > 0.40. More specifically, the lighting level analysis for the rotation angle of 90° on the vertical axis indicates that the plan area exceeding 2% DF is 91.3%, while the uniformity daylight factor is 0.40 UDF. These values satisfy the international standards and thus ensure an efficient working environment in the indoor space under study.

#### ***Daylighting performance results for selected rotation angles***

This section presents an in-depth analysis of daylighting simulated results, i.e. minimum, maximum and average lux level, as well as percentages of the plan area exceeding the daylight levels of 300 lux, 500 lux, 2000 lux and 3000 lux. The analysis focuses on south-facing spaces since they ensure high levels of daylight throughout the year and thus entail

increased possibilities of glare issues. Moreover, south-facing spaces take maximum advantage of direct solar gains during the entire year and thus demand excessive sunlight protection in order to avoid overheating during the cooling period.

More specifically, the system is evaluated on specific horizontal geometrical configurations which, according to the daylighting performance indicators, demonstrate high levels of visual comfort, i.e. rotation angles of 75° and 90°. It is also noted that the respective results of the reference scenario, i.e. spaces without integration of any shading system, are also presented allowing the comparative evaluation of the integrated proposed system. The above-mentioned configurations are investigated for three representative dates of the year and hours of the day, i.e. summer solstice on June 21<sup>st</sup>, spring/autumn equinoxes on March/September 21<sup>st</sup> and winter solstice on December 21<sup>st</sup> at 9.00h, 12.00h and 15.00h.

#### *Horizontal louvers for South orientation*

The lighting level analysis for the selected rotation angles of the proposed louver system during the summer solstice, i.e. 21<sup>st</sup> June, is presented on a comparative basis. As shown in Table 3, the integration of the proposed louver system results to the reduction of the lighting levels of spaces, compared to the reference scenario, i.e. without any shading system. However, the percentage of the plan area exceeding 300 lux remains at high levels, i.e. 100%, during the entire day for both geometrical configurations under study. The daylighting analysis shows that the integration of the system with rotation angle of 75° on the horizontal axis, maintains the percentage of the plan area exceeding 500 lux at high levels, i.e. 88.2% at 09:00h, 100% at 12:00h and 89.7% at 15:00h. At the same time, the rotation angle of 90° on the horizontal axis also demonstrates sufficient lighting levels, with the percentage of the plan area exceeding 500 lux being 79.8% at 09:00h, 100% at 12:00h and 75.2% at 15:00h.

In terms of glare issues, the integration of the proposed system significantly decreases the percentage of the plan area exceeding 3000 lux, compared to the reference scenario in which the percentage of the area exceeding 3000 lux reaches 14.3% during the hours of noon.

Table 3. Lighting levels (lux) for south-facing spaces for selected rotation angles on the horizontal axis during summer solstice, i.e. 21<sup>st</sup> June.

Case Scenario	Lighting levels (lux)				% of space above specific lux level			
	hour	min	max	average	>300	>500	>2000	>3000
Reference	9.00	520.2	2489.0	1150.6	100	<b>100.0</b>	7.1	0.0
	12.00	695.3	3771.2	1721.4	100	<b>100.0</b>	41.2	14.3
	15.00	423.9	2119.4	941.0	100	<b>92.4</b>	1.9	0.0
Horizontal - 75°	9.00	389.1	1426.4	813.2	100	<b>88.2</b>	0.0	0.0
	12.00	619.0	2280.5	1307.8	100	<b>100.0</b>	18.4	0.0
	15.00	487.8	1522.8	901.3	100	<b>89.7</b>	0.0	0.0
Horizontal - 90°	9.00	336.8	1185.2	720.6	100	<b>79.8</b>	0.0	0.0
	12.00	570.3	2119.0	1214.1	100	<b>100.0</b>	7.4	0.0
	15.00	329.5	1252.9	689.3	100	<b>75.2</b>	0.0	0.0

The daylighting analysis for the selected rotation angles of the proposed louver system during the equinoxes, i.e. 21<sup>st</sup> March/September, is presented on a comparative basis. As shown in Table 4, the integration of the proposed louver system results to the reduction of

the lighting levels of the spaces, compared to the reference scenario. However, the percentage of the plan area exceeding 300 lux remains at high levels, i.e. 100%, during the entire day for both geometrical configurations under study. The daylighting analysis shows that the integration of the system with rotation angle of 75° on the horizontal axis, maintains the percentage of the plan area exceeding 500 lux at high levels, i.e. 100% at 09:00h, 99.7% at 12:00h and 79.4% at 15:00h. At the same time, the rotation angle of 90° on the horizontal axis demonstrates reduced lighting levels, with the percentage of the plan area exceeding 500 lux being 77.5% at 09:00h, 77.2% at 12:00h and 61.8% at 15:00h.

In terms of glare issues, the integration of the proposed system significantly decreases the percentage of the plan area exceeding 3000 lux, compared to the reference scenario in which the percentage of the area exceeding 3000 lux ranges from 6.6% to 18.4% at 15:00 and 12:00h respectively.

Table 4. Lighting levels (lux) for south-facing spaces for selected rotation angles on the horizontal axis during equinoxes, i.e. 21<sup>st</sup> March/September.

Case Scenario	Lighting levels (lux)				% of space above specific lux level			
	hour	min	max	average	>300	>500	>2000	>3000
Reference	9.00	562.6	7277.1	1858.2	100.0	<b>100.0</b>	18.8	8.1
	12.00	675.4	10196.3	3000.3	100.0	<b>100.0</b>	29.1	18.4
	15.00	529.9	7150.1	1687.7	100.0	<b>100.0</b>	16.7	6.6
Horizontal - 75°	9.00	520.3	1961.6	1074.4	100.0	<b>100.0</b>	0.0	0.0
	12.00	488.8	2203.4	1076.1	100.0	<b>99.7</b>	0.0	0.0
	15.00	355.3	1653.3	840.8	100.0	<b>79.4</b>	0.0	0.0
Horizontal - 90°	9.00	345.3	1417.5	721.7	100.0	<b>77.5</b>	0.0	0.0
	12.00	365.0	1607.8	831.2	100.0	<b>77.2</b>	0.0	0.0
	15.00	312.7	1338.2	649.9	100.0	61.8	0.0	0.0

Finally, the daylighting analysis for the selected rotation angles of the proposed louver system during the winter solstice, i.e. 21<sup>st</sup> December, is presented on a comparative basis. As shown in Table 5, the integration of the proposed louver system results to the reduction of the lighting levels of the spaces, compared to the reference scenario. However, the percentage of the plan area exceeding 300 lux remains at high levels, i.e. from 80.1% to 100%, throughout the day for both geometrical configurations under study. The daylighting analysis shows that the integration of the system with rotation angle of 75° on the horizontal axis, maintains the percentage of the plan area exceeding 500 lux at high levels, i.e. 97.5% at 09:00h 100% at 12:00h and 64.4% at 15:00h. At the same time, the rotation angle of 90° on the horizontal axis demonstrates reduced lighting levels with the percentage of the plan area exceeding 500 lux being 75.9% at 09:00h, 100% at 12:00h and 46.5% at 15:00h. The results show low percentage of the plan area exceeding 500 lux during the afternoon hours in the cases of both 75° and 90° rotation angles.

In terms of glare issues, in the case of the reference scenario, extremely high percentages of the plan area exceeding 3000 lux are demonstrated, ranging from 4.8% to 74.4%. The integration of the proposed system significantly decreases the percentages of the plan area exceeding 3000 lux, compared to those demonstrated at the reference scenario and thus minimizes glare issues. However, the percentages of the plan area exceeding 3000 lux remain at high levels ranging from 0.0% to 37.4% in the case of 75° rotation angle and from 0.0% to 24.4% in the case of 90° rotation angle.

Table 5. Lighting levels (lux) for south-facing spaces for selected rotation angles on the horizontal axis during winter solstice, i.e. 21<sup>st</sup> December.

Case Scenario	Lighting levels (lux)				% of space above specific lux level			
	hour	min	max	average	>300	>500	>2000	>3000
Reference	9.00	508.6	4668.2	1673.1	100.0	<b>100.0</b>	33.4	27.0
	12.00	934.3	7340.6	3779.3	100.0	<b>100.0</b>	76.7	74.4
	15.00	370.5	3360.8	1084.1	100.0	<b>76.6</b>	18.4	4.8
Horizontal - 75°	9.00	470.1	3906.2	1353.3	100.0	<b>97.5</b>	22.2	18.5
	12.00	705.4	6079.7	2512.8	100.0	<b>100.0</b>	46.3	37.4
	15.00	281.5	2802.8	807.2	100.0	64.4	0.1	0.0
Horizontal - 90°	9.00	328.5	3305.3	905.5	100.0	<b>75.9</b>	10.5	3.0
	12.00	549.5	5510.6	1755.1	100.0	<b>100.0</b>	33.2	24.4
	15.00	237.9	2425.4	625.9	80.1	46.5	3.0	0.0

## Synopsis and Discussion

The present study addresses the visual comfort of existing office buildings in southern Europe. More specifically, the study aims to evaluate the integration of a movable louver shading system for the improvement of visual comfort in terms of both lighting levels and glare issues.

Daylighting performance indicators, i.e. daylight factor and uniformity daylight factor, were first calculated under overcast conditions for different geometrical configurations derived from the rotation of the shading louvres on both the horizontal and vertical axis. The research findings highlight the sufficient lighting levels provided in typical office spaces without any shading system. More specifically, the reference scenario shows that the percentage of the plan area exceeding 2% DF is 100%, however the uniformity daylight factor is rather low, i.e. 0.33 UDF, failing to reach the threshold of 0.40 UDF.

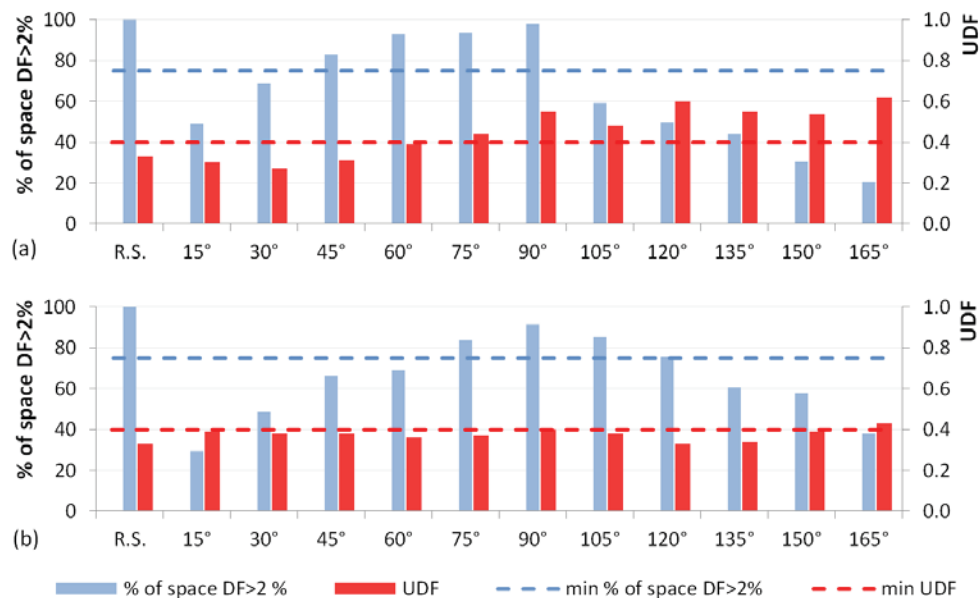


Figure 3. Bar charts show the percentage of the plan area exceeding 2% DF on the left axis and the UDF on the right axis, calculated under overcast conditions for various geometrical configurations derived from the rotation of the shading louvres (a) in the horizontal axis (appropriate for south-facing spaces) and (b) in the vertical axis (appropriate for east- and west-facing spaces) as well as for the reference scenario (R.S.).

As shown in Figure 3a, the daylighting performance analysis, for various geometrical configurations derived from the rotation on the horizontal axis, indicates that rotation angles of 75° and 90° ensure  $DF > 2\%$  for the larger percentage of the plan area ( $> 75\%$ ) and  $UDF > 0.40$ . In the case of the geometrical configuration derived from the rotation on the vertical axis, as shown in Figure 3b, the daylighting performance analysis indicates that only the rotation angle of 90° on the vertical axis ensures  $DF > 2\%$  in a minimum of 75% of the plan areas and of  $UDF > 0.40$ . The above mentioned results satisfy the international standards for indoor visual comfort and thus confirm the positive contribution of the proposed movable system for the improvement of visual comfort, thus ensuring an efficient working environment in existing office buildings.

According to the results derived from the analysis of daylighting performance indicators, an in-depth daylighting analysis was performed for selected rotation angles of the proposed louver system. More specifically, analysis of lighting levels and the percentages of the plan area exceeding specific daylight levels were performed on south-facing spaces for selected geometrical configurations, i.e. rotation angles of 75° and 90°, for three representative periods of the year and three hours of the day. The research findings are summarized in bar charts in Figure 4.

The results indicate that the south-facing space, without the integration of any shading system, i.e. reference scenario, provides high lighting levels in all periods and hours under study. However, high percentage of the plan area exceeds 3000 lux, indicating increased possibilities of glare issues. In the majority of the periods of the year and hours of the day under study, selected rotation angles of the louver system on the horizontal axis ensure high lighting levels. More specifically, the integration of the proposed system during the summer solstice maintains a high percentage of the plan area ( $> 75\%$ ) with lighting levels above 500 lux, in both geometrical configurations under study, i.e. rotation angles of 75° and 90° (Figure 4a). During the equinoxes, the integration of the proposed system at rotation angle of 75° ensures high lighting levels, while in the case of rotation angle of 90° sufficient lighting levels are ensured only during the morning and noon hours (Figure 4b). Finally, the lighting results analysis indicates that the integration of the proposed system during the winter solstice ensures sufficient lighting levels during the morning and noon hours (Figure 4c). Moreover, the integration of the proposed system significantly decreases the percentage of area with more than 3000 lux, during all periods of the year and hours of the day under study and thus drastically minimizes the possibilities of glare issues. It should be noted that according to the daylighting analysis, the percentages of area with more than 3000 lux are totally eliminated during the summer solstice and equinoxes. Despite the drastic decrease of these percentages compared to those demonstrated in the reference scenario, the percentages of the plan area exceeding 3000 lux remain at rather high levels during the winter solstice (Figure 4).

The above simulation results confirm the positive contribution of the proposed louver system in terms of indoor visual comfort, i.e. high lighting levels and reduction of glare issues which ensure efficient working indoor environment as described by international standards. This is in line with relevant literature for the improvement of indoor visual comfort of existing building stock through the integration of external façade systems (Bougiatioti & Michael, 2015; Michael & Heracleous, 2017). Moreover, the study confirms that appropriate geometrical configurations of the proposed system ensure desirable lighting levels during different periods of the year and hours of the day (Michael et al. 2017b; Athienitis & Tzempelikos, 2002). This is in line with research studies showing that



automatically controlled louvres are more effective than fixed ones, in terms of indoor visual and thermal comfort (Tzempelikos & Athienitis, 2007). The above is in line with related studies indicating that the dynamic operation of daylighting and shading systems allows significant improvement of daylight levels and daylight uniformity of indoor spaces and thus improved visual comfort of occupants (Hammad, 2010; Michael et al., 2016).

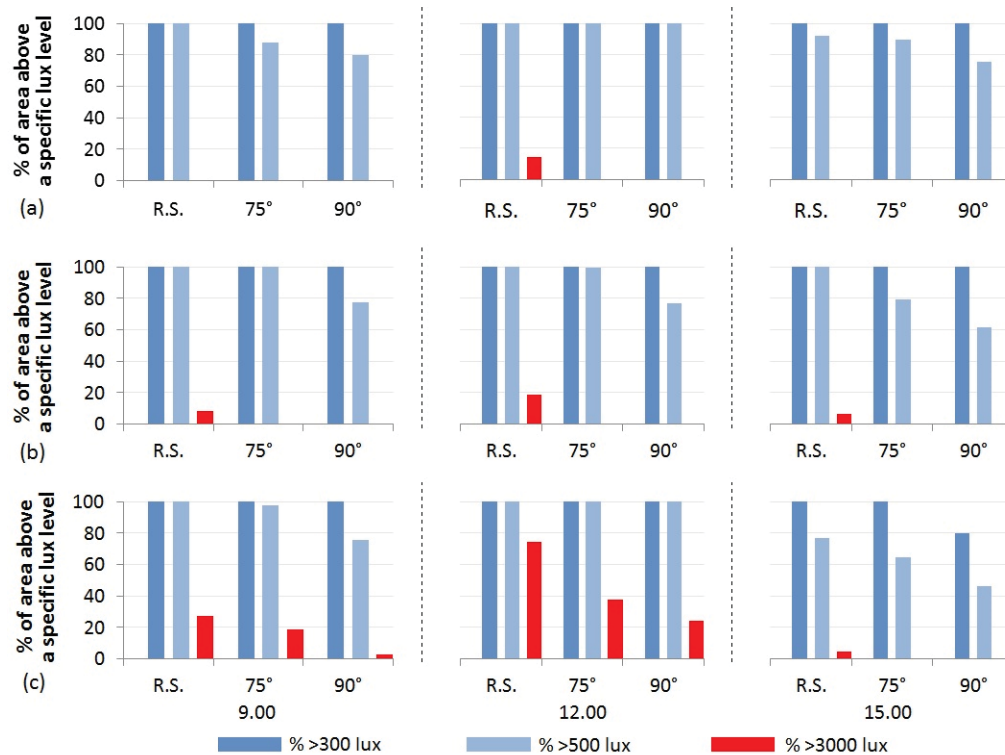


Figure 4. Bar charts showing the percentages of the plan area exceeding specific daylight levels demonstrated on south-facing spaces for selected geometrical configurations, i.e. rotation angles of 75° and 90° on horizontal axis, as well as for the reference scenario (R.S.), i.e. spaces without any shading system, during (a) summer solstice, (b) equinoxes and (c) winter solstice, at 09:00h, 12:00h and 15:00h.

## Conclusions

The analysis of the simulation results allow the comparative evaluation of indoor visual comfort, indicating the appropriate rotation angle of the louver system in both the horizontal and vertical axis for the improvement of visual comfort for different periods of the year and hours of the day. Regarding the daylighting performance indicators, the analysis shows that appropriate geometrical configurations on both the horizontal and vertical layout of the proposed system allow high percentages (> 75%) of the plan area exceeding 2% DF, while at the same time, they ensure high levels of daylight uniformity of indoor spaces with UDF exceeding the threshold of 0.40. Moreover, the investigation of lighting levels performed for south-facing spaces shows that, in the majority of cases under study, the integration of the proposed system allows high levels of daylighting in the indoor space, with daylight levels exceeding 500 lux for more than 75% of the plan area, thus, satisfying international lighting standards. Moreover, the integration of the proposed system eliminates extremely high daylight levels (> 3000 lux) and thus, minimizes the possibility of glare issues.

The above research findings indicate that the integration of the proposed daylighting system ensures high daylight levels and uniformity of indoor spaces, which in effect, improves the visual comfort of occupants. At the same time, it contributes to the reduction

of energy consumption results from the use of artificial lighting. It is also noted that the research findings can also be applied in other areas of southern Europe with similar climatic characteristics and building typologies. Further research would allow the investigation of the positive contribution of the integrated façade system in terms of shading and insolation during the cooling and heating period respectively, thus improving the thermal performance of the buildings under study. These findings will provide possibilities for a holistic environmental renovation method for the existing office building stock.

## References

- Almussaed, A. & Almssad, A., (2014). Natural lighting efficiency by means of sun-sky-light-tubes. *International Journal of Engineering and Advanced Technology*, 3 (3), pp. 16-20
- Athienitis, A. & Tzempelikos A., (2002). A methodology for simulation of daylight room illuminance distribution and light dimming for a room with a controlled shading device. *Solar Energy*, 72 (4), pp. 271-281
- Bougiatioti, F., Michael, A., (2015) The architectural integration of active solar systems. *Building applications in the Eastern Mediterranean region, Renewable and Sustainable Energy Reviews* 47, pp. 966-982
- BREEAM. Health and Wellbeing. Hea 01 Visual Comfort, Available: [http://www.breeam.com/BREEAM2011SchemeDocument/Content/05\\_health/hea01.htm](http://www.breeam.com/BREEAM2011SchemeDocument/Content/05_health/hea01.htm)
- CIE, Spatial distribution of daylight - CIE standard general sky, Commission Internationale de l'Eclairage, ISO 15469:2004 (E)/CIE S 011/E:2003
- CIBSE, Daylighting and Window Design, Lighting Guide LG10, Chartered Institution of Building Services Engineers, 1999, London
- CIBSE, Environmental Design-CIBSE GUIDE A, Chartered Institution of Building Services Engineers, 2015, Norwich
- Grynning, S., Time, B. & Matusiak, B. (2014). Solar shading control strategies in cold climates – Heating, cooling demand and daylight availability in office spaces. *Solar Energy*, 107 (2014), pp. 182-194
- Hammad, F. (2010). The energy savings potential of using dynamic external louvers in an office building, *Energy and Buildings*, 42 (2010), pp. 1888–1895
- IESNA, Illuminating Engineering Society of North America, *Lighting Handbook*, 9th ed., 2000, New York
- IEA, International Energy Agency, (2009), Available: <http://www.iea.org>
- Janssen, R. (2004). Towards energy efficient buildings in Europe. In: *EuroACE 2004*, London, UK, 20 - 21 December 2016. Docklands: University of East London
- Michael, A.G., Alexandrou, K.C., Konatzii, P.G, Kalli, A.K, (2016) An Environmental Renovation Strategy based on Adaptive Control Optimisation of a Modular Light Regulating Façade System. *The Built Environment*, 161 (2016), pp. 71-82
- Michael, A., Heracleous, C., (2017) Assessment of natural lighting performance and visual comfort of educational architecture in Southern Europe. The case of typical educational school premises in Cyprus, *Energy and Buildings* 140 (2017), pp.443–457
- Michael, A., Heracleous, C., Thravalou, S., Philokyrou, M., (2017a) Lighting performance of urban vernacular architecture in the East-Mediterranean area: Field study and simulation analysis, *Indoor and Built Environment*, 26/4, pp. 471-487
- Michael, A., Gregoriou, S. & Kalogirou, S., A. (2017b). Environmental Assessment of an Integrated Adaptive System for the Improvement of Indoor Visual Comfort of Existing Buildings, *Renewable Energy* Available online 18 July 2017, In Press.
- Nielsen, M.V., Svendsen, S. & Jensen, L.B. (2011). Quantifying the potential of automated dynamic solar shading in office buildings through integrated simulations of energy and daylight. *Solar Energy*, 85, pp. 757-768
- Palmero-Marrero, A. & Oliveira, A. (2009). Effect of louver shading devices on building energy requirements. *Applied Energy*, 87 (2010), pp. 2040-2049
- Poirazis, H., Wall, M., Blomsterberg, A. (2008). Energy simulations for glazed office buildings in Sweden. *Energy Build*, 2008 (40), pp. 1161-70
- Selkowitz, S. & Lee, E., (2004). Integrated automated shading and smart glazing with daylight controls. In: *International Symposium on Daylighting Buildings*, IEA SHC TASK 31, Tokyo, Japan
- Radhi, H., Eltrapolsi, A. & Sharples, S. (2009). Will energy regulations in the Gulf States make buildings more comfortable – a scoping study for residential buildings. *Applied Energy*, 86 (12), pp. 2531-9
- Tzempelikos A. & Athienitis, A., (2007). The impact of shading design and control on building cooling and lighting demand. *Solar Energy*, 81 (2007), pp. 369-382

# Sustainable Architectural Design of the Central Mediterranean

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**Abstract:** The climate of the central Mediterranean archipelago of Malta is characterised by hot dry summers and cold humid winters. For centuries, the architecture of these geoheritage islands, erected in the local limestone, has addressed the physical characteristics arising from the topography. This industrial mineral, the source of dimension stones for the building construction industry since time immemorial, is being depleted at a rapid rate.

The Islands have a significant stock of buildings which, due to growing public awareness, development planning policies and central government initiatives for heritage protection, are being restored, conserved and re-used. This paper explores contemporary sustainable residential architecture completed in recent years in existing urban contexts from environmental, technical and financial perspectives. Adopting a holistic approach to architectural design, bioclimatic and passive considerations would enhance the environmental quality of the existing built environment. Integrating them in the redevelopment through modifications and extensions to existing buildings in order to meet contemporary habitable standards rather than demolishing and developing new residential developments proved to be a viable option from all three perspectives. The resulting sustainable design solution optimizes on energy and land resources through minimising the impact/s on the natural environs which future generations will be enjoying. In addition to having healthier interiors, a prerequisite for the human wellbeing of users, such an approach is financially more remunerative. Based on case studies, this study concludes that energy site sensitive environmental design decisions integrated in existing residential properties is a secure socio-economic investment in the built heritage. The re-designed modifications and extensions are not only sustainable in terms of thermal and natural lighting but also in terms of building materials and construction techniques.

**Keywords:** sustainable design, bioclimatic design, passive design, Central Mediterranean, Malta

## Introduction

Sustainable architectural design optimises natural and energy resources and addresses the wellbeing of citizens. It promotes quality of the indoor and outdoor environments by reducing the negative aspects on same (Iwaro and Mwasha, 2013). A widely held working definition of sustainable development is the one included in the report of the Brundtland Commission which was chaired by the Norwegian Prime Minister Gro Harlem Brundtland (Redclift, 2009; Petrovic et al, 2010; Petrovic et al, 2011a; Petrovic et al, 2011b; Radojicic et al, 2012; Sobczyk, 2014; Mortada, 2016). It defines sustainable development as a "... development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission of Environment and Development, 1987). Environmental, economic and social aspects, all impacting on health and the wellbeing of society, must all be considered and integrated in such a development (Hendriks, 2001; Radojicic et al, 2012). Sustainable development entails a transgenerational perspective focusing on the impact on being and the welfare of each citizen (Dragomirescu and Bianco, 2017).

Sustainable architecture creates and sustains a healthy, energy efficient, built environment, thus optimising on natural and renewable resources (Lányi, 2007). Worldwide architecture accounts for 40-50% of waste generation deposited in landfills and 50% of all the raw materials extracted from the earth surface by weight (Wines, 2008). Sustainable

architectural design is an approach of designing the built environment in conformity with the principles of socio-economic and ecological sustainability (McLennan, 2004).

Several recent studies on sustainable design were published (e.g. Soflaei et al, 2017a; Mortada, 2016). This paper explores from environmental, technical and financial perspectives contemporary sustainable residential architecture design from the Maltese Islands completed in recent years with respect to a residential unit in Żabbar and Nadur on Malta and Gozo respectively (Figure 1).



Figure 1. The Maltese Islands (a) and orthophotos: locations of case studies are circled in red (Source: Planning Authority, Malta) (b).

## The Maltese archipelago

### *Contextual background*

Malta is the main island within the Maltese archipelago, a group of islands covering 316m<sup>2</sup> and located almost at the centre of the Mediterranean, circa 100km south of Sicily and 300km north of Libya (Figure 1). The second largest island is Gozo. The climate is typically Mediterranean with mild, wet and humid winters and warm to hot dry summers (Mitchell and Dewdney, 1961; Chetcuti et al, 1992; Schembri, 1997). The islands are generally sunny with occasionally high winds. The mean temperature is the warmest in Europe: circa 23°C and 16°C during the day and at night respectively. Large fluctuations are rare. The typical daytime temperature in the shade is, on the low side, 12°C in winter and, at the highest end, 34°C in summer. At night the temperature may respectively be 7°C and 24°C (Galdies, 2011). With respect to daylight hours, the shortest amount is around 10 whilst the longest is around 15, whilst sunshine hours which total to circa 3,000 annually are at a mean of over 5 hours and 12 hours in the winter and summer months respectively. Mean yearly precipitation is around 600 mm: heavy showers occur generally in autumn and winter (Galdies, 2011).

Traditional, notable vernacular, architecture of the Maltese Islands is a response to this climate. Its architectural and building history evolved through the various occupations through its political history (De Lucca, 1993), the last being Britain (1800-1964). Yet, the rural and urban texture of the Islands is more akin to the Middle East; residential architecture is typically inward-looking with organic patterned urban winding streets and alleys (Bianco, 2016). The traditional residential typology of Malta prior to the advent of the British was the courtyard house. It is the urbanized version of the rural 'razzett', a farmhouse cubic in massing. This rural typology recalls the building forms along the southern Mediterranean basin and suggests the source of the tradition prior to the arrival of the Knights of the Order of St John (1530-1798) (De Lucca, 1993). Despite the influences

from Europe, notably Sicily, the word for 'open-air market' and for 'square' are 'suq' and 'misraħ' recalling Semitic origin albeit the romance word 'piazza' is also used.

Vernacular architecture is humane, pragmatic and addresses the wellbeing of the users (Bianco 2016). It comprises of "... dwellings and other buildings of the people. Related to their environmental contexts and available resources, they are customarily owner- or community-built, utilizing traditional technologies. All forms of vernacular architecture are built to meet specific needs, accommodating the values, economies and ways of living of the cultures that produce them" (Oliver, 1997). It is "architecture of the people, and by the people, but not for the people" (Oliver, 2003), a claim supported by the global survey of vernacular architecture published by Noble (2007). It is sustainable in terms of durable, low-maintenance, energy sensitive constructions. The traditional courtyard house so fitting to the Maltese climate was effectively abolished following the introduction of the terraced house typology made mandatory through the sanitary laws and regulations enacted in the latter half of the nineteenth century (Laws of Malta, 1854), the main urban planning legislation until the enactment of the 1992 *Development Planning Act* (Aquilina, 1999). The sustainability of the courtyard model has been the subject of recent publications (Keskin and Erbay, 2016; Manioğlu and Koçlar Oral, 2015; Soflaei et al, 2016; Soflaei et al, 2017a; Soflaei et al, 2017b). The typology of the terraced house, with back gardens and occasionally front ones, is not ideal for the central Mediterranean as it was developed for colder climates where conserving rather than cooling the building is required. Unfortunately this typology was reinforced by Legal Notice 227 of 2016 (Laws of Malta, 2016). "As courtyard houses were replaced by row houses, their introverted centrality gave way to a street-oriented polarity between a symbolic 'front' addressed to outsiders and a functional 'back' for family life. .... The Middle-Eastern perception of the street as no-man's land between intensely private domains was replaced by the baroque perception of the street as theatre" (Tonna, 1997). Yet the traditional terraced house is still suitable in terms of low-maintenance building materials and through the use of architecture features to cut down on sunlight intake in the summer months.

### ***Traditional construction materials and building techniques***

Since the Neolithic period the built heritage of the Malta is a statement of the main industrial mineral of the archipelago, the Lower Globigerina Limestone (LGL), which outcrops over a significant part of Malta and Gozo (Bianco, 1995). It is the oldest member of the Globigerina Formation, a Miocene carbonate sedimentary limestone of shallow marine origin. The characteristic honey-coloured dimension stone, the medium in which the rich architectural legacy of the islands is realized, is extracted from this formation.

Traditional building construction in line with the nineteenth century legislation has a number of significant considerations. These include the following:

1. Walls, effectively in LGL dimension stones, are either single or double-skin. The latter has a wide cavity resulting in an overall thickness of just less than 2 feet (60.96cm) for walls exposed to the elements thus the outer skin will serve as an environmental skin against rain and sun. This was enforced especially for habitable rooms;
2. The floor to ceiling height for habitable rooms was set at a minimum of 2.7m although effectively it varied between 3.0 and 3.3m;
3. Introducing of damp proof course; and



4. Well for rain water collection from the roof; water from backyard was to be drained onto the public street.

This legalisation was implemented in toto for constructions post 1880. Prior to this legislation, walls were also either single or double-skin. Instead of bonding them via a bond stone, they were infilled with inert construction rubble and had an overall thickness of circa 3 feet (91.44cm) (Quentin Hughes, 1967), the minimum being 2.5 feet (76.20cm) (Tonna, 1997). As damp proofing, the lower courses up to circa 1.2m above the level of the ground were constructed in the harder Coralline Limestone which is less absorbent than LGL (Bianco, 1999). Due to shortage of timber the lower floors were roofed over by LGL roofing slabs ('xorok') supported by LGL masonry arches. The ribs were supported by double-skin walls to take the side thrust of the arch (Mahoney, 1996). This type of construction method was still used following 1880. Given that timber beams were more available, and later steel beams, they were used at ground floor level as well. Reinforced concrete roofs were introduced in the 1950s (Tonna, 1997). The mode of tiling had not changed much in residential architecture until the later part of the twentieth century.

Roofs in Malta are traditionally flat. They are constructed similarly to the other floors with a 3 to 4 inches (7.6 to 10.32cm) layer of limestone chippings laid to uniformly distribute the load on top of which another 0.25 inches (6mm) layer of fine chippings with lime-cemented pottery shards was added (Quentin Hughes, 1967; Tonna, 1997). The layer had a slight incline for rain water runoff to drain to a well for storage for potable use. In vernacular residential architecture the well used to be in the courtyard; in nineteenth century terraced houses it was located in the internal yard whilst and for inter-war houses it was placed in the backgarden. Although still compulsory at law, contemporary developments are doing away with wells and instead they drain rain water either directly onto the public street or to the public sewer, both are unsustainable solutions.

## Methodology

Two residential units whose building footprint predated 1880 were studied. Both won an international award of the International Academy of Architecture for innovation in traditional architecture:

1. house at 20, Misraħ is-Sliem, Żabbar, Malta (WGS84 coordinates: 14.577169, 35.874464), hereafter referred to as Żabbar House (Figure 2a, b and c) and
2. house at Triq il-Knisja corner with Triq Piju Cellini, Nadur, Gozo (WGS84 coordinates: 14.292030, 36.038399), hereafter referred to as Nadur House (Figure 2d, e and f).

The re-designed modifications and extensions to both tenements for contemporary residential use were undertaken in 2000 and 2012 for the Żabbar and Nadur house respectively (Figure 2). Both were originally substandard for habitation. Although located in a pedestrian space within the village core, the two-storey Żabbar House could not be sold due to its sheer size and condition. Both levels are constructed in traditional masonry blocks roofed over by masonry roofing slabs supported by timber beams (Figure 2a). In terms of contemporary development planning policies, the height limitation for urban conservation area (UCA) is limited to two floors and a washroom at roof level. A case was made with the planning regulator for an additional floor in line with other building heights and uses of properties bordering the misraħ. The architectural work involved alterations and extension (Figures 2b, 2c and 3a) (Anon, 2013). The philosophy of restoration and rehabilitation applied complies with the *Teoria del Restauro* of Cesar Brandi (1963).

The Nadur House is located just outside the UCA. As per local development planning policies, the allowable height is limited to three floors plus penthouse and a three metre front garden along one side of the site (Malta Environment and Planning Authority, 2006). Originally it was a dilapidated one-storey masonry structure, essentially a ruin forming part of a *razzett* with later post Second World War additions erected in poor masonry construction (Figure 2a). The redevelopment utilizes the notion of the ruin and memory as the main basis of its design (Gauci, 2009). Rather than opting for a block of apartments in a saturated neighbourhood, the design involved the restoration and integration of the ruin in the extension of the house (Figures 2e, 2f and 3b).



Figure 2. Żabbar House: before (a) and after (b and c); Nadur House: before (d) and after (e and f).

The massing of the Nadur House recalls the vernacular Maltese farmhouse. The general characteristics of the renovated residential units are given in Table 1. In this study, these two houses were

- i. evaluated for the sustainability in their re-design as per Wilhide (2002) and Keskin and Erbay (2016); and
- ii. assessed with respect to the costs involved in the construction of modifications and extensions in traditional materials and methods and finishing of same to contemporary habitable standards.

Similar costings as (ii) above were undertaken with respect to each site assuming that the house were to be demolished and erected to the allowable height limitation as per development planning policies, sanitary engineering legislation and contemporary building construction and materials which makes use of single-skin walls of concrete blocks roofed over by reinforced concrete slabs.

There are various schools of thought on how the cost-value of a given immovable property is estimated. The method used in this study is based on the cost of constructing and finishing.

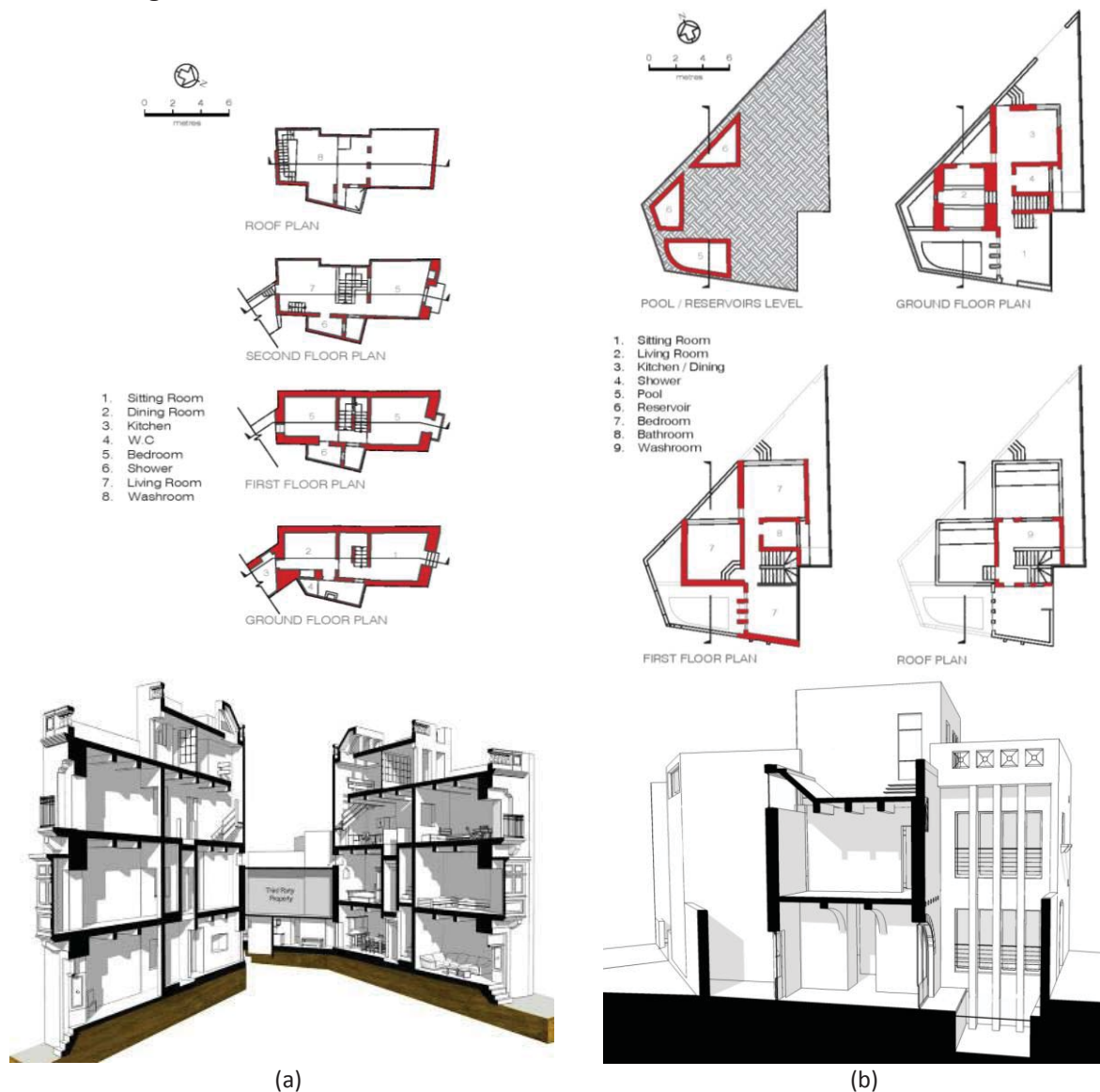


Figure 3. Layout and sectional perspective: Žabbar House (a) and Nadur House (b).

Table 1. General characteristics of renovated traditional residential units.

Characteristics	Żabbar House	Nadur House
Settlement	Rectangular plot with the shortest side overlooking the misraħ is north facing to optimise daylight; the number of small apertures on the south wall is low to block sunlight; no apertures on the east and west third parties walls	Site is a triangular corner; orientation of the dwelling is such to minimise sunlight whilst maximising daylight and air convention currents; a 2m high perimeter wall to property is present
Planning layout	Living spaces are at ground floor level whilst bedrooms, including another family living room, are at the upper levels	Living spaces are at ground floor level whilst bedrooms are at the upper level
Built form	Form is compact with the upper level stepped back from the main elevation to minimise visual impact	Compact cubic form recalling the vernacular architecture of the Maltese Islands
Site impact	Although the resulting dwelling is on three-storeys, the building heights around the misraħ vary; retaining the original colour helped to complement the character of this part of the square. The external masonry walls of the additional level are left unrendered	The building integrates with the existing urban environment in terms of scale; its massing, fenestration and features, most notably the sundial, render it a landmark to the neighbourhood

## Results and discussion

The analysis of the architectural design, construction materials and methods used in both the Żabbar House and the Nadur House is the given in Table 2. The interventions undertaken are in conformity with planning and sanitary regulations; thus the tenements were upgraded from substandard to residential units fit for habitation. Furthermore, in both cases, the number of residential units was not increased and thus there was no increase in the density of dwelling units with no corresponding increase in car parking provisions.

A comparative valuation of the properties based on the cost of construction and finishes and the current market values of same as per website <http://www.propertymarket.com/> is given in Table 3. The values of the Żabbar House and Nadur House are compared to the values of properties on same respective sites if demolished and rebuilt as per contemporary widespread practice. The computed valuation is based on (i) the current values for land within the limits of development, (ii) the cost of building construction, including demolition, excavations and carting away, (iii) the cost of mechanical and electrical systems (M&Es) and (iv) the cost of finishes. The rate for traditional materials and construction is circa 25% higher than the standard rate. Also, given the site configuration and the required setback at law from street elevations, neither a penthouse nor a washroom may be erected at the Nadur site. Due to the site location of the Żabbar House and Nadur House the cost of the land is respectively 50% and 100% higher than the base rate of €400.00/m<sup>2</sup>.



Comparing the valuation of the properties based on the cost and finishes with the market values of similar tenements, the percentage tolerance indicative of the financial risk involved was established. The option of demolishing and re-building the sites as per allowable local planning policies in contemporary materials and construction is less secure.

Redevelopment of substandard and/or derelict buildings and sites instead of demolition is viable. Beyond the indicator model to determine the revitalisation of derelict property proposed by Zavadskas and Antucheviciene (2006), the Żabbar House and the Nadur House illustrate an aspect of sustainable architecture beyond re-using and recycling of traditional building materials. Applying an integrated approach to architectural design within UCAs has not only environmental and technical significance but also a financial merit.

Table 2. Energy design efficiency and building methods and materials.

	Żabbar House	Nadur House
Energy design efficiency	<ol style="list-style-type: none"> <li>1. North lights at roof of washroom serve as light scoop; pivot windows ensure a breeze in the summer months through air convection currents through the upper levels of the house which have a roof and third party walls facing east and west exposed to the elements</li> <li>2. No windows opening onto south facing wall</li> <li>3. Internal shaft creates stack effect</li> <li>4. Roofs to original bedroom have internal ambient temperature</li> </ol>	<ol style="list-style-type: none"> <li>1. The corner of the plot is west facing: all apertures facing this direction are narrow to cut down on heat from the low lying sun</li> <li>2. North facing, high level windows at the upper level with pivot type apertures serve as light scoops thus maximising daylight, eliminating sunlight and encouraging air circulation at this level whose roofs are exposed to the elements</li> <li>3. South facing openings are deep in section to cut down on the sunlight during the summer months</li> <li>4. Cross-ventilation is provided by apertures facing one another</li> </ol>
Building materials	<ol style="list-style-type: none"> <li>1. All works were undertaken in traditional construction except for the roof to the washroom as the floor to ceiling height imposed by the planning regulator did not allow for timber beams to be used</li> <li>2. Original walls are thick thus having high thermal capacity; such walls were used in the main elevation of the additional floor</li> <li>3. Original construction materials used in the stairwell to roof were reused in the new floor</li> <li>4. Dimension stones for additional construction were traditional but not recycled</li> <li>5. Recycled timber beams and masonry roof slabs were used</li> </ol>	<ol style="list-style-type: none"> <li>1. Dimension stones from the demolished rooms were re-used in the construction</li> <li>2. Other building materials are all traditional but none are recycled</li> <li>3. Construction waste removed from the site comprised roofs of derelict rooms erected in the latter part of the twentieth century and excavation material from the swimming pool; the latter, a source of concrete aggregate, was transported to a local crusher for aggregate production</li> </ol>



Table 3. Comparative valuation of property based on cost of construction and finishes.

	Żabbar			Nadur		
	Traditional House		Option to rebuild	Traditional House		Option to rebuild
	Existing	Extension		Existing	Extension	
Area (m <sup>2</sup> )						
site	44	44	44	164	164	164
Front garden	0	0	0	75	0	58
Back garden	117	0	117	0	0	0
Buildable levels above ground	106	53	106	23	152	318
Washroom	0	26	25	0	23	0
Basement	0	0	44	0	0	164
Pool/reservoirs	0	0	0	0	35	0
Site cost (in €)						
Buildable levels <sup>a</sup>	63600	47400	105000	18400	140000	385600
Front garden <sup>b</sup>	0	0	0	15000	0	11600
Back garden <sup>b</sup>	11700	0	11700	0	0	0
Cost of works (in €)						
Demolition/ excavation/carting <sup>c</sup>	0	0	6000	0	500	2300
Construction <sup>d</sup>	15900	11850	21000	3450	26250	57840
Pool/reservoirs <sup>d</sup>	0	0	0	0	4200	0
Cost of M&Es (in €)						
Buildable levels above ground <sup>e</sup>	8480	6320	10480	1840	14000	25440
Basement <sup>f</sup>	0	0	1760	0	0	6560
Pool/reservoirs <sup>f</sup>	0	0	0	0	1400	0
Cost of finishing (in €)						
Buildable levels above ground <sup>g</sup>	21200	15800	26200	4600	35000	63600
Basement <sup>h</sup>	0	0	4400	0	0	16400
Pool/reservoirs <sup>h</sup>	0	0	0	0	3500	0
	121147	81493	182476	43552	221724	553644
Total value (in €)		202640	182476		265276	553644
Market value (in €)		240000	160600		293000	525000
% Tolerance		16	-14		9	-5

<sup>a</sup> €400.00/m<sup>2</sup>; <sup>b</sup> €100.00/m<sup>2</sup> (0.25\*€400.00/m<sup>2</sup>); <sup>c</sup> sum; <sup>d</sup> €120.00/m<sup>2</sup>; <sup>e</sup> €80.00/m<sup>2</sup>;

<sup>f</sup> €40.00/m<sup>2</sup> (0.5\*€80.00/m<sup>2</sup>); <sup>g</sup> €200.00/m<sup>2</sup>; <sup>h</sup> €100.00/m<sup>2</sup> (0.5\*€200.00/m<sup>2</sup>)

Sustainable architectural design has to address the real-estate market but also the socioeconomic realities of Malta (Bianco, 2016). Climatic conditions, natural energy and building resources utilised, and compatibility with site topography are common characteristics of such a design. Akin to vernacular architecture whereby human-nature relation is resolved in elementary, effective and functional manner (Keskin and Erbay, 2016), the Żabbar House and the Nadur House address the prevailing existing environmental

conditions, whether daylight, sunlight and/or thermal capacity of the building materials thus leading to less utilisation of energy resources and lower utility electricity bills related to heating and lighting. The orientation of the buildings is dictated by the existing layout of their respective footprint. In the terraced houses of Malta, the ideal orientation is north-south; the east-west axis should be avoided and windows facing in either direction should be kept small (Cutajar, 1989). At Żabbar House the orientation complies with such an arrangement. In the case of the Nadur House orientation went beyond passive design, the traditional solution used for thermal conform and daylight levels. The redevelopment evokes the site, its memory and its location in time and place. From a technical perspective, the resulting buildings are high in endurance; traditional materials and construction are low maintenance, durable, weather well and have nil fire-loading. Such building materials and engineering lead to lower insurance premium.

Malta has the highest population density amongst EU Member States (European Commission). It has a significant stock of empty residential units (National Statistics Office, 2014). New real-estate development of apartments within UCA impacts on the urban infrastructure. Demolishing existing units and constructing a new block of apartments at a given site increases the density of residential units and the corresponding augmentation in car parking provisions.

The analysed houses illustrate sustainable architectural design based on the comprehension of the anatomy of a given building on site. The interventions are in local materials and methods and respecting the climatic parameters of the site, aspects acknowledged for their significance in traditional architecture (Özmehmet, 2005; Keskin and Erbay, 2016), and prove that such interventions are financially viable. The contemporary practice of demolition and construction new residential developments is a less secure investment in monetary terms than opting for a traditional heritage sensitive design. This challenges the popular perception that it is more financially rewarding to demolish and re-erect a new building especially within UCA. Furthermore, given that these houses were recipients of international design awards, their inherent financial value is augmented, thus increasing the tolerance in monetary terms and hence ensuring a safer investment. Long term, they are likely candidates for scheduling which further sustains culture heritage for future generations.

## Conclusions

This study evaluates two recent development projects involving traditional houses in the Maltese Islands from environmental, technical and financial perspectives. It concludes that contemporary sustainable architectural design in traditional building materials and construction on existing footprint is a viable option from all these aspects:

1. Environmental:
  - i. Integrating bioclimatic and passive considerations in redevelopment through modifications and extensions to existing buildings enhance the quality of the built environment; and
  - ii. No increase in the number of residential units and thus no increase in mandatory car parking provisions;
2. Technical:
  - i. Use of low maintenance, durable local materials and sturdy load-bearing masonry construction tested through time; and
  - ii. Reduction of inert construction waste;

### 3. Financial:

- i. Modifications and extensions to traditional residential units congruent with the built environment are more secure real-estate investment than demolishing and developing new residential developments; and
- ii. Given that building materials are durable and weather well and the construction is robust, insurance premiums are lower.

Architectural design can transcend the mere compliance with local development planning policy. A sustainable approach aimed at the wellbeing of the occupiers is secured through the use of traditional methods of construction, materials and environmental physics. Site sensitive environmental design with respect to existing residential properties is a socio-economic investment in the built environment.

## References

- Anon (2013). A home for an architect. *The Architect*, February 2013, p. 17.
- Aquilina, K. (1999). *Development Planning Legislation: The Maltese Experience*. Malta: Mireva Publications.
- Bianco, L. (1995). The industrial minerals of the Maltese islands: A general introduction. *Hyphen*, 7(3), pp. 111-118.
- Bianco, L. (1999). Geocultural activity in seventeenth and eighteenth century Malta. *GeoJournal*, 48(4), pp. 337-340.
- Bianco, L. (2016). Rural and urban vernacular architecture of the Mediterranean: A source for contemporary, contextual, architectural design solutions. In: *The 5th Electronic International Interdisciplinary Conference 2016*, 8-12 August 2016, pp. 126-131. Slovakia: University of Zilina.
- Brandi, C. (1963). *Teoria del Restauro*. Torino: Einaudi.
- Chetcuti, D., Buhagiar, A., Schembri, P. J. and Ventura, F. (1992). *The climate of the Maltese Islands: a review*. Msida, Malta: Malta University Press.
- Cutajar, A. (1989). *The thermal environment in terraced houses in Malta*. B.E.&A.(Hons). University of Malta.
- De Lucca, D. (1993). Maltese vernacular architecture: A living tradition? In: *Companion to Contemporary Architectural Thought*, Farmer, B., Louw, H. (eds). London and New York: Routledge, pp. 210-214.
- Dragomirescu, H. and Bianco, L. (2017). Tackling sustainability from a systemic perspective: A contextualized approach. *Problemy ekoro-zwoju/Problems of Sustainable Development*, 12(1), pp. 31-39.
- European Commission, Eurostat: *Tables, Graphs and Maps Interface Table*. <http://ec.europa.eu/eurostat/tgm/table.do?tab=table&language=en&pcode=tps00001&tableSelection=1&footnotes=yes&labeling=labels&plugin=1>. Retrieved 24 August 2017.
- Galdies, C. (2011). *The Climate of Malta: Statistics, trends and analysis 1951-2010*. Malta: National Statistics Office.
- Gauci, R. (2009). *Architecture 4D soul: Maltese dwellings: signs of hope for the 21st century human being and his domicile*. B.E.&A.(Hons), University of Malta.
- Hendriks, C.H. (2001). *Sustainable construction*. Bostel: Aeneas Technical Publishers.
- Iwaro, J. and Mwasha, A. (2013). The impact of sustainable building envelope design on building sustainability using Integrated Performance Model. *International Journal of Sustainable Built Environment*, 2(2), pp. 167-272.
- Keskin, K. and Erbay, M. (2016). A Study on the Sustainable Architectural Characteristics of Traditional Anatolian Houses and Current Building Design. Urban Planning and Architecture Design for Sustainable Development, UPADSD 14- 16 October 2015. *Procedia - Social and Behavioral Sciences*, 216, pp. 810 – 817.
- Lányi, E. (2007). The basic principles of sustainable architecture. *Periodica Polytechnica Architecture*, 38(2), pp. 79-81.
- Laws of Malta (1854). *Code of Police Laws*.
- Laws of Malta (2016). *Legal Notice 227 of 2016: Development Planning (Health and Sanitary) Regulations*.
- Mahoney, L. (1996). *5000 Years of Architecture in Malta*. Valletta: Valletta Publishing.
- Malta Environment and Planning Authority (2006). *Gozo and Comino Local Plan*. Malta: MEPA.

- Manioğlu, G. and Koçlar Oral, G. (2015). Effect of Courtyard Shape Factor on Heating and Cooling Energy Loads in Hot-Dry Climatic Zone. 6th International Building Physics Conference, IBPC 2015. *Energy Procedia*, 78, pp. 2100 – 2105.
- McLennan, J. F. (2004). *The philosophy of sustainable design: the future of architecture*. Kansas City, Mo: Ecotone.
- Mitchell, P. K. and Dewdney, J. C. (1961). The Maltese climate and weather. In: Bowen Jones, H., Dewdney, J. C. Fisher, W. B. (eds). *Malta, a background for development*. Durham: Durham University Press, pp. 48–82.
- Mortada, H. (2016). Sustainable desert traditional architecture of the central region of Saudi Arabia. *Sustainable Development*, 24, pp. 383-393.
- National Statistics Office (2014). *Census of Population and Housing 2011: Final Report*. Valletta: NSO.
- Noble, A.G. (2007). *Traditional Buildings: A Global Survey of Structural Forms and Cultural Functions*. London and New York: I.B. Tauris & Co.Ltd.
- Oliver, P. (1997). *Encyclopaedia of Vernacular Architecture of the World*. Cambridge: Cambridge University Press, pp. xxi-xxviii.
- Oliver, P. (2003). *Dwellings: The vernacular house worldwide*. Oxford: Phaidon.
- Özmehmet, E. (2005). *A Building Model Suggestion for Mediterranean Climate Type in the Context of Sustainable Architecture*, M.Sc.. Dokuz Eylül University (in Turkish).
- Quentin Hughes, J. (1967). *The Building of Malta during the period of the Knights of St John of Jerusalem*. London: Alec Tiranti.
- Petrovic, N., Isljamovic, S. and Jeremic, V. (2010). Zero waste as a new concept for sustainable development. *Management*, 15(57), pp. 39-45.
- Petrovic, N., Isljamovic, S., Jeremic, V., Vuk, D. and Senegacnik, M. (2011a). Ecological footprint as indicator of students environmental awareness level at Faculties of Organizational Sciences, University of Belgrade and University of Maribor, *Management*, 16(58), pp. 15-21.
- Petrovic, N., Drakulic, M., Vujin, V., Drakulic, R. and Jeremic, V. (2011b). Climate changes and green information technologies. *Management*, 16(59), pp. 35-43.
- Radojicic, Z., Isljamovic, S., Petrovic, N. and Jeremic, V. (2012). A novel approach to evaluating sustainable development. *Problemy Eko-rozwoju/Problems of Sustainable Development*, 7(1), pp. 81-85.
- Redclift, M.R. (2009). Sustainable Development (1987-2005) – an oxymoron comes of age. *Problemy Ekorozowju/Problems of Sustainable Development*, 4(1), pp. 33-50.
- Schembri, P. (1997). The Maltese Islands: climate, vegetation and landscape. *GeoJournal*, 41(2), pp. 115-125.
- Sobczyk, W. (2004). Sustainable development of rural areas. *Problemy Eko-rozwoju/Problems of Sustainable Development*, 9(1), pp. 119-126.
- Soflaei, F., Shokouhian, M. and Zhu, W. (2016). Socio-environmental sustainability in traditional courtyard houses of Iran and China. *Renewable & Sustainable Energy Reviews*, 69, pp. 1147–1169.
- Soflaei, F., Shokouhian, M. and Soflaei, A. (2017a). Traditional courtyard houses as a model for sustainable design: A case study on BWHS mesoclimate of Iran. *Frontiers of Architectural Research*, 6, pp. 329-345.
- Soflaei, F., Shokouhian, M., Abraveshdar, H. and Alipour, A. (2017b). The impact of courtyard design variants on shading performance in hot- arid climates of Iran. *Energy and Buildings*, 143 (2017) pp. 71–83.
- Tonna, J. (1997). Malta. In: Oliver, P. (ed.), *Encyclopedia of Vernacular Architecture of the World*. Cambridge: Cambridge University Press, pp. 1560-1562.
- Wilhide, E. (2002). *Eco: An essential sourcebook for environmentally friendly design and decoration*. London: Quadrille Publishing Ltd.
- Wines, J. (2008). Green Architecture: Building for the 21st Century: Year in Review 2007. *Encyclopædia Britannica*. Encyclopædia Britannica Online. Encyclopædia Britannica Inc., 2017. <<https://www.britannica.com/topic/Green-Architecture-Building-for-the-21st-Century-1382132>. Retrieved 22 August 2017.
- World Commission of Environment and Development (1987). *Our Common Future*. New York: Oxford University Press.
- Zavadskas, E. K. and Antucheviciene, J. (2006). Development of an indicator model and ranking of sustainable revitalization alternatives of derelict property: A Lithuanian case study. *Sustainable Development*, 14(5), pp. 287–299.

# Analysis of non-uniform cavity configuration of the double façade on heat stratification

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**Abstract:** Energy consumption of buildings over the world is approximately 40% of the total world annual energy consumption. In hot arid climate, cooling loads acts to be the influential part of energy consumption. Building envelope plays an important role in promoting energy saving in building. Nowadays architecture aims to shift towards passive strategies to decrease the energy demands. The double facade technology is introduced by several leading architects as an energy conscious architectural technology. The notion is to have a deep vision for the cavity thickness of double skin facade for its steady/constant pattern through the entire height. Properly design for the cavity, by alternation in its configuration, may have a serviceable influence on the amount of heat transfer, which consequently enhances the operative temperature inside the cavity, subsequently, affect the adjacent occupied spaces. The new approach is intending to boost the double skin facade prevalent morphology for its steady cross section, to generate an autonomous non-uniform cavity. Diversity in percentage of shading devices is proposed to provide variation in amount of controlling solar heat gain. The pattern is generated parametric pattern that provide numerous degree of alternatives based on geometric process. Optimization through amalgamation of cavity configuration and percentage of shading is observed. A developed notion is proposed to decrease the operative temperature within the cavity of the double skin facade. The connotation determines the solar radiation analysis grid on the facade using simulation and performance analysis tool, which is used to drive design decision. The aim is to monitor the influence of the proposed system on reducing heat transfer and its impact on achieving thermal comfort with low energy consumption. The Double skin facade can significantly reduce the heat gain through the building as the cavity act as intermediate layer through decreasing transmitted heat and intense solar radiation.

**Keywords:** Double Skin Façade, Solar radiation, Heat transfer

## Introduction

The double skin façade is a passive method introduced in high-end European and Pacific Rim Architecture. The system is composed of an external and internal skin constructed as partially of fully glazed material, separated by the cavity channel. The main notion is to reduce heat gain during summer by extracting the trapped heat from upper vents while maintaining heating purpose in winter, where the cavity acts as thermal buffer to reduce heat loss and provide thermal gain. The heat flow in the cavity channel is investigated through radiation, convection and conduction heat transfer. Multiple parameters summarized in; ventilation pattern, shading mode cavity width, cavity height, vent openings, the glass optical property, have a consequential effect on the heat stratification inside the cavity. Through the research concentration on two prime parameters, cavity configuration and percentage of shading is analyzed and discussed. Geometric parameter of cavity configuration and diversity in the shading percentage have an influence on the air flow and heat transfer, exerting gradient in the temperature profile inside the cavity.



## Double skin facade

The double facade system plays an important role in reducing the impact of high solar gains that affect the temperature inside the cavity during warm season. The cavity notion assists in acting as an intermediate zone between the occupied space and the external environment, trying to achieve the required modulation for decreasing heating and cooling load on the building. Diversity in parameters affects the airflow through the channel of the Double skin facade.

The double facade acts as indirect passive system that can remove the trapped air inside by forced convection, enabling aerodynamics interconnection through the cavity with the outside environment. Theoretically the flow condition is classified into two domains buoyancy alone or buoyancy and wind combined assisting buoyancy source (Gan 2010). The double façade is considered as a solar chimney, where the air inside the chimney is warmed up. Natural ventilation is generated through the double by activation of the stack effect that occurred with a particular distribution of the openings. (Ding, Hasemi et al. 2005). Fresh air is introduced through certain openings from windward side to pass through the occupied space then discharged into the double skin cavity, till exhausting from the outlet on the top of the chimney, due to increase in temperature at the chimney channel that create difference in pressure, Figure (1).

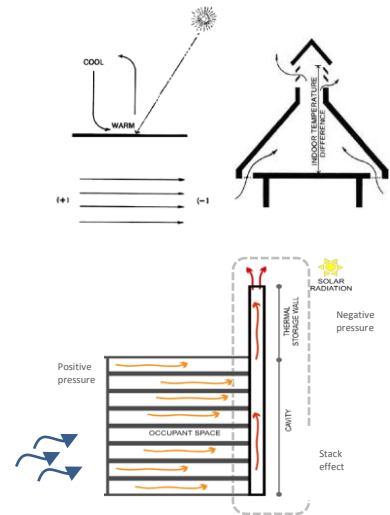


Figure1. Different strategies of airflow

## Design parameters of Double skin facade

Several parameters on different scales have generated an influence on the airflow rate inside the cavity of the double facade as there is no standard guideline to evaluate the performance of DSF. Site and facade are the main taxonomy for the facade parameters. Site parameters compromise the wind speed and direction together with solar irradiance and orientation. Wind plays an important role as a key natural driving stimulus for the thermal and airflow behavior of the DSF, which consequently affect the ventilation, due to difference in pressure generated (Lou, Huang et al. 2012).

## Façade Parameters

Facade parameters have a considerable impact on thermal aspects of building strategies. Proper design for the geometrical elements of the facade as cavity depth, height and configuration have a significant influence in reducing building energy consumption, Figure (2).

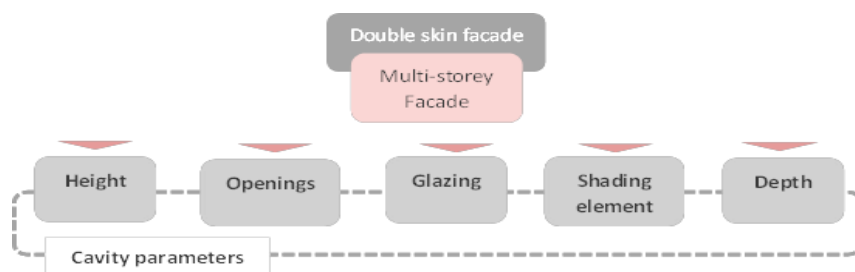


Figure2. Cavity parameters affecting performance of DSF

Cavities with a narrow depth generate an accentuated stack effect and a robust air movement which leads to extraction of the warmer air through the cavity. Studies show that the diversity in the cavity depth has an influence on the indoor temperature and energy consumption in buildings. The depth cavity varied from 10cm to more than 2m; count on the design concept such as the availability of shading devices, cavity maintenance and cleaning and its effect on the rate of air flow (Rahmani, Kandar et al. 2012). From 0.7m till 1.3m is the recommended cavity depth that creates a balance between air extraction and heat transmission to the occupied space. This happens due to the accentuated stack effect occurring inside the cavity which enhances the ventilation rate and result in less demand for cooling (Radhi, Sharples et al. 2013). Many attempts are introduced to examine the influence on changing of the flow channel configuration on buoyancy and heat stratification in the double skin facade. Similarity in the behavior in the cavity and its influence on indoor thermal and air quality conditions is observed (Hamza, Cook et al. 2011).

The cavity height is one of the prime parameters that manipulate the magnitude of the stack effect in DSF due to the generated difference in height between inlet and outlet openings of the cavity (56\_perspective). In warm climate, the taller cavity, the higher extraction of excessive heat due to higher speed generated (Quesada, Rousse et al. 2012). The precedent studies emphasize that the increase in the thermal storage space produce increase in pressure between the upper and lower part of the cavity especially the upper floor (Ding, Hasemi et al. 2005). In the pressure difference between the upper and lower inlets is generated within the increase of the height of thermal storage, chimney height exceeds 5m of the, resulting in higher rate of airflow cavity (Gratia and De Herde 2004). For achieving thermal comfort with no mechanical system, its recommended to implement the thermal storage space extended two floors height to promote natural ventilation (Barbosa and Ip 2014). At multi-storey façade a high temperature gradient is caused along the cavity, moving the heat up rapidly (Torres, Alavedra et al. 2007).

Moreover, Glazing has a significant role in providing the required daylight and visual connection; meanwhile it can cause extremist inconsiderate heat gain resulting in thermal comfort. Chou observed that window to wall ration ranges from 0.5 to 0.7 cause attenuation in the overall annual heat transfer for the building, while an increase was monitored for the model with window to wall ratio of 0.9 (Chou, Chua et al. 2009). Selective nomination for the properties of glazing is essential for well balance between the buoyancy effect in the cavity and heat gain in occupied space should be considered as function of the thermal performance required. The double glazing pane is recommended as well insulation glazing material diminishing the heat exchange through spaces for energy saving in Mediterranean climate (Torres, Alavedra et al. 2007). Precedent shows that implementation of low-emissivity glass for the internal glazing can increase the attenuation of the solar loads. While, one of the cases tested by Chan et al. reviews that using single glazing on the inner skin in conjunction with double glazing at the outer layer is effective in reducing heat gain through the cavity and consequently to the building (Chan, Chow et al. 2009).

The cavity opening is one of the prime factors affecting DSF performance. At multi-storey façade a high temperature gradient is caused along the cavity, moving the heat up rapidly (Gan 2010). An interrelation between the openings dimensions, air flow and air temperature. Lower temperature is observed cavities with large openings at with higher airflow rate (Gratia and De Herde 2007). Increasing the height between the openings generate high difference in pressure that assist in removing trapped air inside the cavity.

Adjustable shading devices are amalgamated in the cavity flow channel for thermal control. Argue is always raised that blinds is usually high as an advantage in cold regions and a challenge in hot areas. It is use to reduce heat gain and protect the interior space from increased cooling load(Wong 2008). The shading devices assist in regulating the solar incidence reaching the occupied space by decreasing heat gain loads. Three scenarios were previously introduced for positioning the shading devices inside the cavity; close to the inner glazing, close to the outer glazing and at the middle of the cavity. Placing the blinds closing to the inner layer was not recommend as higher heat is transferred from the cavity due to the larger amount of transmitted to the indoors. Well established thermos circulation is created on both sides of the blind when located at the middle of the cavity (Jiru, Tao et al. 2011)Despite of the fact that the shading devices are located in most scenarios inside the cavity for respecting several aspects as structure and maintenance, the performance of external blinds is still far superior compared to internal one due reducing a large amount of heat to be transmitted from the external glazing, or acting as an obstacle for air flow (Gonçalves 2010).

### Cavity Impact Factors

The airflow entering the facade summarizes the resistance of the facade to the total airflow through the cavity, where the total difference in pressure is considered the difference in pressure between the inlet and outlet of the facade cavity.

The outlet airflow of the cavity is created due to difference between the flow inside the cavity and the ventilation flow through window (Stec and Van Paassen 2003).

The prime parameters for assessing the impact of the convective heat transfer inside the cavity, due to the complex factors that affect its performance, are: The air temperature inside the cavity; it is affected by the connective heat transfer at the surfaces and the shading devices. The strength of the buoyancy strongly depends on the air temperature and thus on the convective heat transfer at the surfaces. The higher temperature, the higher strength of the buoyancy force will result (Mingotti, Chenvidyakarn et al. 2013). Rate of air flow; Randomness and extremely fluctuating nature are the aspects that define the wind forces. The two main driving forces affecting airflow inside the cavity are:

- Buoyancy force that is caused by the temperature difference between the air inside and outside the cavity of the double facade
- Wind effect that generates the pressure difference between the inlet and outlet of the facade
- Where the mass flow rate in the cavity depends on the applicability for the naturally ventilated in the double skin facade, where the driving forces (wind and buoyancy) may counteract or act together (Ghaffarianhoseini, Ghaffarianhoseini et al. 2016).

### Methodology

The research focuses on the geometric of the cavity as a one of the parameters that affect building performance employing simple constituent aspects. Diversity in the geometric morphology of the cavity can assist in improving the air movement, based on the principle of Venturi effect that decrease the pressure at the constricted part boosting the movement of the airflow inside the cavity, figure (3).

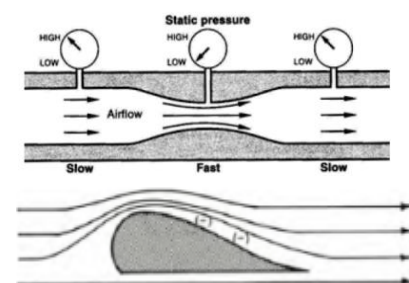


Figure 3. The air flow increases as its static pressure decreases

Comparison between the three different proposals of the façade configuration is analyzed, evaluating the influence of the alternative on the thermal performance of the cavity. Through precedent research the cavity is proposed with constant thickness through the entire height, although variation in cavity depth proposes fluctuation in the flow through the channel. Simulation will be carried using honeybee plugin, as thermal analysis software to detect the influence of the proposed approach on the operative temperature of the occupied spaces, Figure (4).

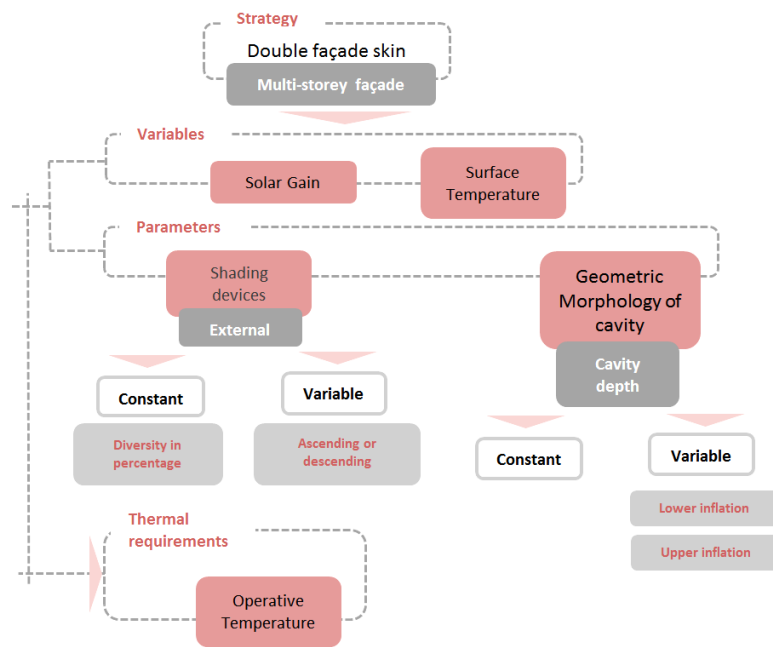


Figure4. A Diagram shows the Methodology of the research

### Modeling the proposed façade

The aim of the research is to achieve thermal comfort with low energy consumption in the building, by removing the trapped heat gain in the cavity by convection. The geometrical design is generated at grasshopper focusing on alternative cavity configuration and diversity in percentage of shading, where the outer skin will propose irregular cavity depth through the entire height together with external shading devices extracted from parametric origami pattern. The glazing layer defines the cavity configuration through the entire height with specific properties, double glazed with low e-coating to decrease the heat transfer by reducing radiative and conductive heat transfer for warm climate (Mingotti, Chenvidyakarn et al. 2013).

Since the prevailing wind is blowing from East North, the air is allowed to enter the space from a lower inlet opening at NE to be directed to the double skin façade from an upper outlet opening at the opposite side. In addition to the lower opening of the double skin façade elevated 2.5m above the ground level avoided from any obstruction. The height of the cavity exceeds the building height by 3m for boosting air flow, where the inlet and the outlet openings is located the lower and upper part of the cavity respectively.

## Computation workflow

The design is proposed using computational parametric software, together with real-time environmental analyses which provide instant feedback as the design progresses. Software used includes Grasshopper, ladybug and honeybee plug-in. The performance norm selected to evaluate the performance of the double facade is the operative temperature inside the space, which is affected directly by the cavity configuration and the percentage of shading applied to the façade.

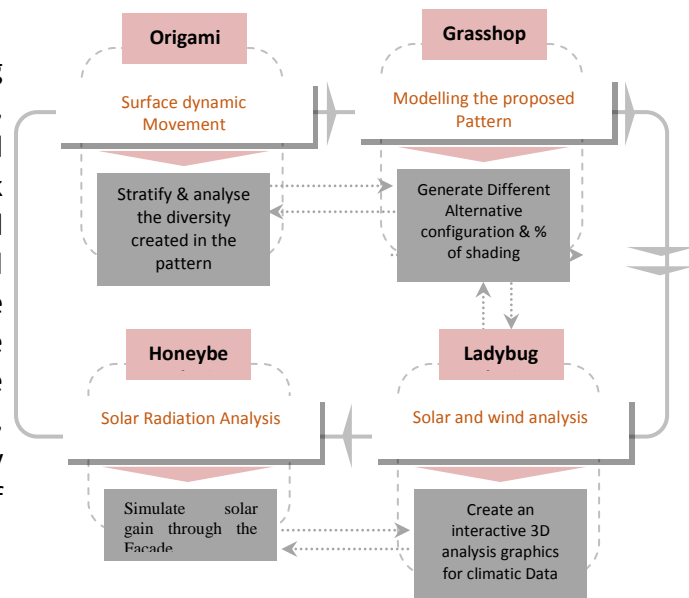


Figure5. A Diagram shows the flow of the simulation process

- Grasshopper is a graphical algorithm editor tightly integrated with Rhino's 3-D modelling tools.
- Ladybug is an open source environmental plug-in, which creates an environmentally-conscious architectural design through a variety of interactive 3D graphics to associate the decision making process in the early design stage.
- Honeybee fasten grasshopper 3D to Energy plus, Radiance and several software's for building energy and daylight simulation in a parametric approach, Figure (5).

## Building Description

The simulation will be held for an office building design prototype at Cairo in Egypt, with latitude is 30.13, longitude is 31.40 and elevation latitude is 74.0. It is a prototype four storey building, with curtain wall facing south west. It is subjected to high solar radiation intensity, especially from April till October. The simulation will be applied on the south West facade. The analysis will offer a comparison between applying a normal double skin facade and the proposed one. The conventional double facade is constructed within a constant cross-section air gap between the two layers of the façade.

## Cavity Configuration

Two proposals are introduced for alternative cavity configuration to be compared with the regular cavity; the lower inflation which create inflation portion at the channel inception and the upper inflation where the channel configuration is reversed creating the constricted portion at the channel inception. From 0.7m to 1.7 m is the range of the cavity thickness. The glazing layer defines the cavity configuration through the entire height with specific properties, double glazed with low e-coating to decrease the heat transfer by reducing radiative and conductive heat transfer for warm climate (Mingotti, Chenvidyakarn et al. 2013), Figure (6).





Egypt has experienced rising in air temperature in the recent years due to the increase in night temperatures which has been rising at higher rates. Egypt climate is semi-desert characterized by hot dry summer and moderate winter. Ladybug for Rhino is the plug-in used for providing weather analysis using weather data generating sun-path diagram and global solar radiation charts to provide a comprehensive solar, thermal and light analysis function.

### Solar Analysis

In Egypt, The solar radiation intensity annual is high through the entire year, where solar radiation is very high in summer. The average temperature remains above 28°C most of the year coincides with solar radiation more than 755 WH/m<sup>2</sup>. The average temperature attains 32°C corresponding to solar high solar radiation 863 WH/m<sup>2</sup> at the mid-day stretching around 2 hours before and after. The 3D chart visualizes the number of hours for the comfort zone with temperature above 28°C, Figure (9).

### Wind Analysis

Wind-rose is used to analyze the wind speed and direction, where the dominant is out of the North direction. The wind blows from the North East direction with average speed 4.9 m/s from North East direction most of the year, denoting that the North façade is considered the windward side of the building. Seasonal prevailing wing wind occurs in the duration form October till February blowing from the South West direction, which can be exploited at our ventilation strategy, Figure (10).

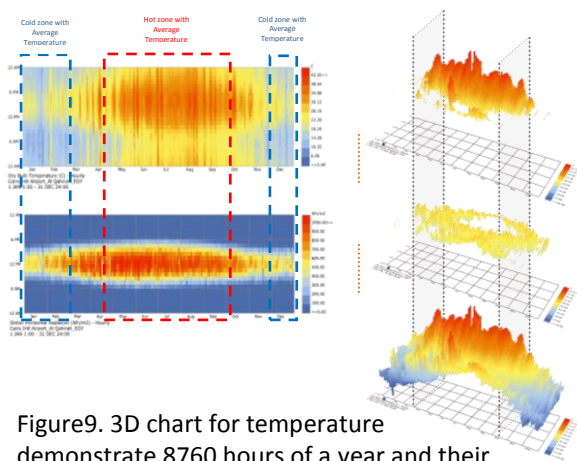


Figure9. 3D chart for temperature demonstrate 8760 hours of a year and their analysis

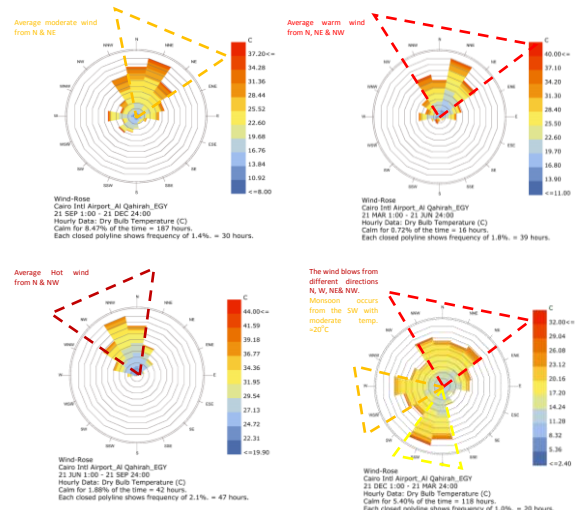


Figure10. Average wind temperature through four the whole year

### Thermal Simulation

The simulation is carried along a fragmented period showing diversity in the climatic factors. 21st of May and August at 13:00 are nominated for simulation for having variation in the temperature and solar radiation that influences indoor thermal quality, where the dry bulb temperature equal to 30°C and 33.4°C respectively. Honeybee 0.059 plug-in for thermal modelling is integrated to deduce the impact of solar radiation on the internal surface of the cavity, taking into account radiation heat transfer and conduction through facade component. From diversified list of zone program provided by Honeybee estimating internal gain of the occupied zone which assigned as an open office with number of people at peak occupancy is 0.056 ppl/m<sup>2</sup> and efficient lighting equipment loads ranges 11.4 W/m<sup>2</sup>.

## Simulation for thermal performance of DSF alternatives

21<sup>st</sup> of August

Dry bulb Temperature = 34°C

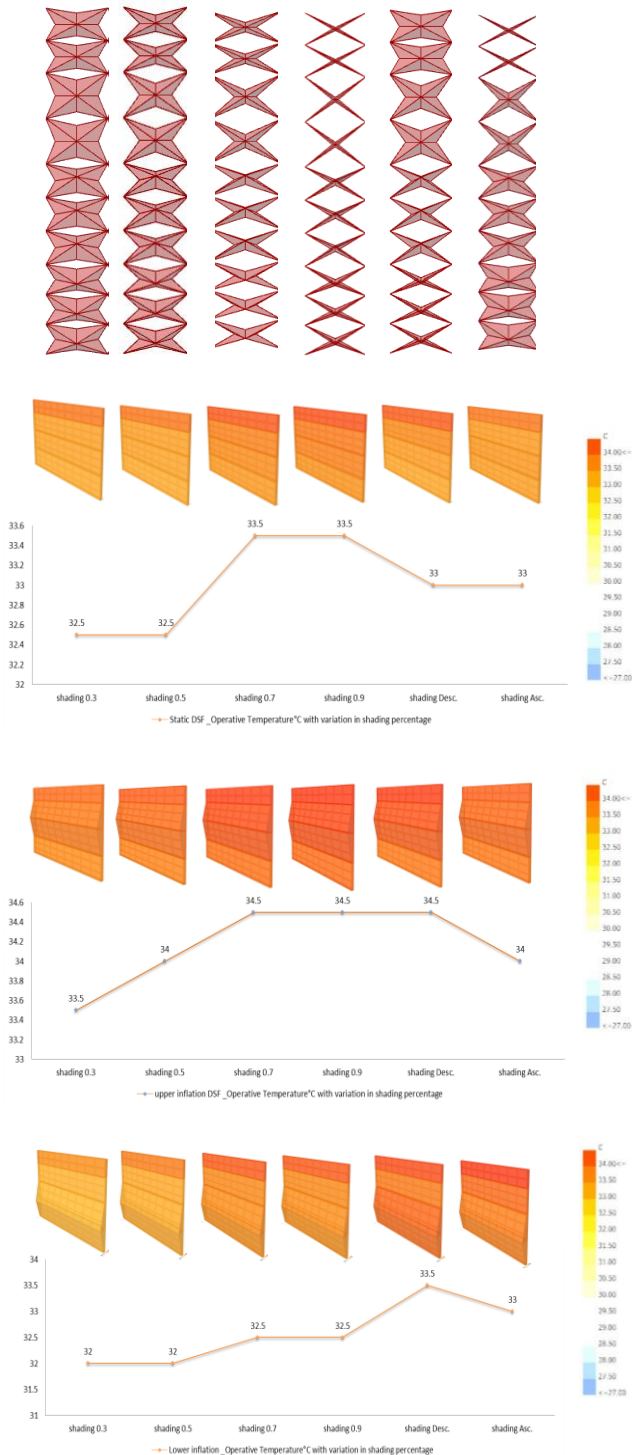


Figure11. Graphs demonstrating operative temperature for diversity in shading percentage in August

21<sup>st</sup> of May

Dry bulb Temperature = 30°C

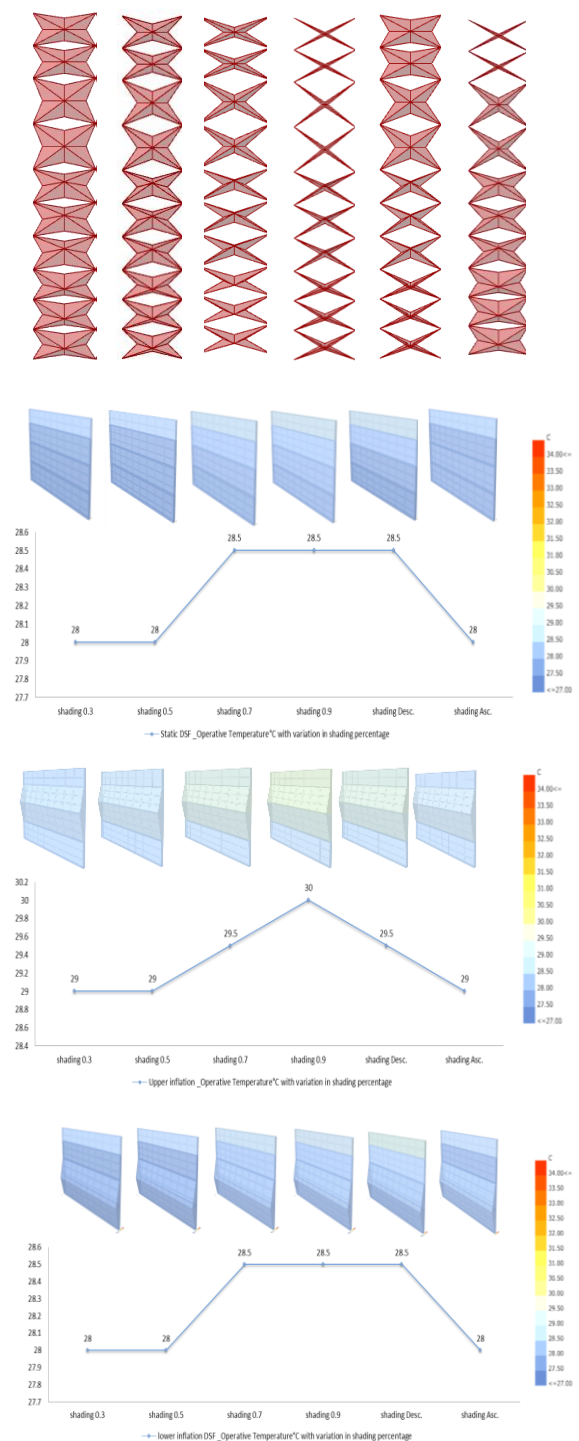


Figure12. Graphs demonstrating operative temperature for diversity in shading percentage in May

Through Honeybee simulation "Set EP airflow" component is applied to model "multi-zone" natural ventilation so long as there are no major vertical differences in height over multiple zones and the user understands that "mixing objects" of constant air flow are used to distribute cool incoming air between zones that are connected by an air wall.

## **Results**

The comparative analysis for the results is shown in graphs Table (1&2). Thermal results show divergence in the operative temperature, between high and low percentages of shading. The operative temperature inside the cavity of the double façade without the shading devices is 31°C in May and 36°C in August.

The double façade acts as an intermediate zone to decrease the impact of the external climate on the occupied zones. The lower inflation emphasizes on the air flow principle; the Venturi principle, as the constricted part at the upper part may assist in removing more trapped heat inside the channel by increasing the rate of air flow inside the cavity and consequently decrease the operative temperature recorded through the simulation.

### ***Shading devices***

The idea of proposing the parametric pattern for shading elements is to balance daylight provision and solar heat gain to maintain comfort level. The geometrical pattern of the origami generates a depth characterizing its folded form that always provides shading for the façade. Such characteristic recorded 2 degrees difference in temperature in May and August when compared with un-shaded one, while obtaining maximum visual connection. The Ascending scenario (low percentage of shading at the upper part) records low temperature than the descending one, due to the higher difference in temperature; higher solar gain at the upper part of the chimney (cavity) from low percentage of shading.

Alternative configuration with percentage of shading equals to 0.7 and 0.9 always coincide with lowest operative temperature with appropriate daylight penetrating the space, as the shading devices is almost opened compared with similarities. Through monitoring the operative temperature for the DSF shading alternatives in August, keeping the 0.7 shading percentage as the baseline, a fluctuation in temperature is observed, where the highest temperature is always recorded at the upper part (chimney height), figure (12, 13).

### ***Cavity depth***

Comparing results of thermal analysis with the static DSF (baseline prototype), the following is observed:

- In August, a remarkable reduction at operative temperature is observed predominantly at the lower inflation DSF (32.5°C), counted around 1°C degree reduction. The upper inflation recorded the higher operative temperature (34.5°C), higher than the static one. A high resemblance between the static and the double inflation observed (33.5°C) in temperature or even higher.
- In May, the Static façade recorded the lower degree temperature as the lower inflation equals to 28.5°C, while the upper inflation is the highest operative temperature around 29.5°C and more, Table (1, 2).

Table1. Comparison between different percentages of shading through cavity configuration in August

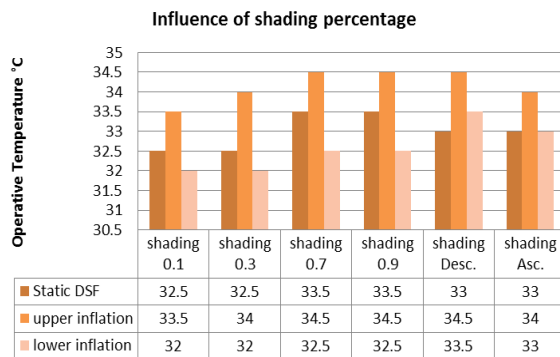


Table2. Comparison between different percentages of shading through cavity configuration in May

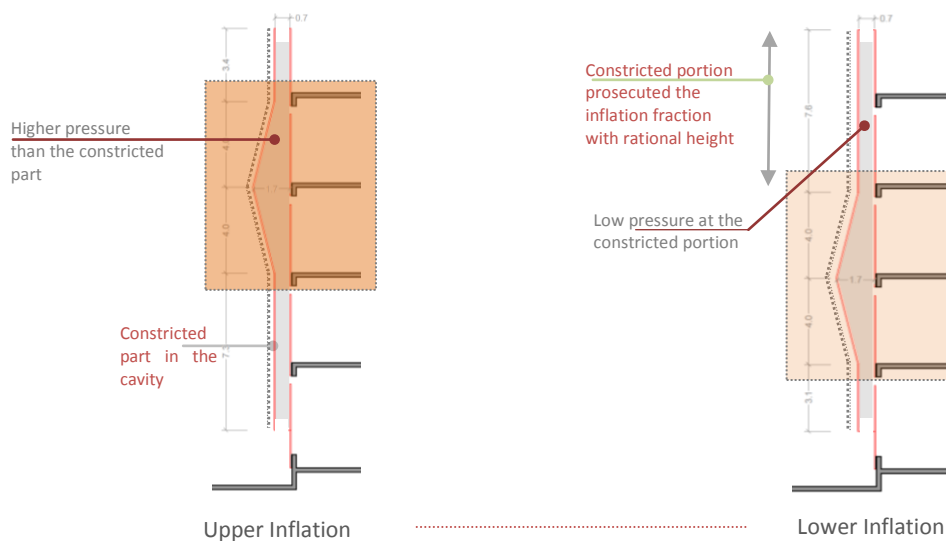
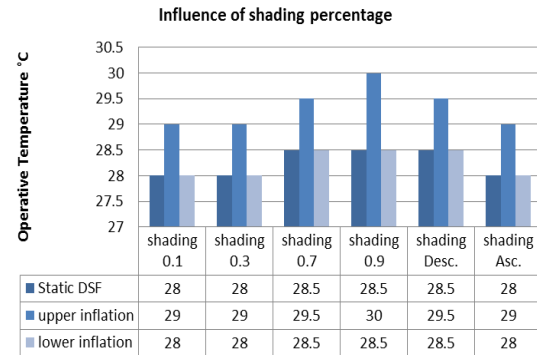


Figure13. Analysis for the pressure difference between the two cases (lower & upper

The upper part of the cavity (chimney) always recorded the highest temperature. At the lower inflation, the inflation portion of the cavity recorded the lowest temperature when compared to the other scenarios. Such result is ratiocinated either from the constricted part prosecuted the inflation portion with a rational height that increase the rate of air flow (Venturi's effect) or due the capacious depth of the cavity that reduce the ration of the solar heat gain at this cavity fraction. For rigorous conclusion, the results should be investigated by computational fluid dynamic simulation.

At the upper inflation, a large amount of heat gain is trapped inside the cavity due increase in depth at the upper part which leads to increase in pressure, attenuating the movement of the air assembled at the constricted part. This results in higher degree in temperature through the entire height of the cavity, Figure (13).

## Conclusion

Double skin facades has significant role in thermal performance of space due to their influence on heating and cooling loads of occupied spaces. The results emphasize on the connotation of providing sufficient amount of daylight with low percentage of shading, almost opened, while maintain a slight increase in operative temperature ranges around 1°C. Due to the geometrical pattern of the origami, which generate a depth characterizing its



folded form, that always provide shading for the façade, even its totally opened together with obtainable visual connection. Such variation exerts a slight impact on the internal surface temperature, counted around 0.5°C degree. The study shows that diversity in the cavity configuration has a substantial impact on the air flow which enhances the operative temperature inside the cavity. The lower inflation prototype recorded lower operative temperature especially in August, which emphasizes on the importance of integrating the air flow principles within geometrical design of the cavity and its influence on the air flow to improve thermal aspect of the space naturally. More studies and simulation is required to investigate the air flow inside the cavity to understand its influence on the operative temperature and consequently affect the occupied zones as the double façade act as an intermediate zone to decrease the impact of the external climate.

## References

- Barbosa, S. and K. Ip (2014). "Perspectives of double skin façades for naturally ventilated buildings: A review." *Renewable and Sustainable Energy Reviews* 40: 1019-1029.
- Chan, A., et al. (2009). "Investigation on energy performance of double skin facade in Hong Kong." *Energy and Buildings* 41(11): 1135-1142.
- Chou, S., et al. (2009). "A study on the effects of double skin façades on the energy management in buildings." *Energy Conversion and Management* 50(9): 2275-2281.
- Ding, W., et al. (2005). "Natural ventilation performance of a double-skin façade with a solar chimney." *Energy and Buildings* 37(4): 411-418.
- Gan, G. (2010). "Interaction between wind and buoyancy effects in natural ventilation of buildings." *Open Construction and Building Technology Journal* 4: 134-145.
- Ghaffarianhoseini, A., et al. (2016). "Exploring the advantages and challenges of double-skin façades (DSFs)." *Renewable and Sustainable Energy Reviews* 60: 1052-1065.
- Gonçalves, J. C. S. (2010). *The environmental performance of tall buildings*, Routledge.
- Gratia, E. and A. De Herde (2004). "Optimal operation of a south double-skin facade." *Energy and Buildings* 36(1): 41-60.
- Gratia, E. and A. De Herde (2007). "Greenhouse effect in double-skin facade." *Energy and Buildings* 39(2): 199-211.
- Hamza, N., et al. (2011). *Comparative Analysis of Natural Ventilation Performance in Non-Uniform Double Skin Facades in Temperate Climates*. *Proceedings of Building Simulation*.
- Jiru, T. E., et al. (2011). "Airflow and heat transfer in double skin facades." *Energy and Buildings* 43(10): 2760-2766.
- Lou, W., et al. (2012). "Experimental and zonal modeling for wind pressures on double-skin facades of a tall building." *Energy and Buildings* 54: 179-191.
- Mingotti, N., et al. (2013). "Combined impacts of climate and wall insulation on the energy benefit of an extra layer of glazing in the facade." *Energy and Buildings* 58: 237-249.
- Quesada, G., et al. (2012). "A comprehensive review of solar facades. Transparent and translucent solar facades." *Renewable and Sustainable Energy Reviews* 16(5): 2643-2651.
- Radhi, H., et al. (2013). "Will multi-facade systems reduce cooling energy in fully glazed buildings? A scoping study of UAE buildings." *Energy and Buildings* 56: 179-188.
- Rahmani, B., et al. (2012). "How Double Skin Façade's Air-Gap Sizes Effect on Lowering Solar Heat Gain in Tropical Climate?" *World Applied Sciences Journal* 18(6): 774-778.
- Stec, W. and A. Van Paassen (2003). *Defining the performance of the double skin facade with the use of the simulation model*. *Proceedings of Building Simulation*.
- Torres, M., et al. (2007). "Double skin facades-Cavity and Exterior openings Dimensions for Saving energy on Mediterranean climate." *IBPSA Proceedings of Building Simulation*: 198-120.
- Wong, C. (2008). "Natural ventilation in double-skin façade design for office buildings in hot and humid climate." *University of New South Wales, Australia*.

# **“Green Pockets” as Microclimate Modifiers in UK Urban Schools**

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**Abstract:** The rapid densification of many UK cities poses significant pressure on the design of schools within inner city centres. London's air quality has been associated with increasing mortality and pollution while noise levels have exceeded acceptable standards. As a consequence, most schools are mechanically ventilated and have little to no contact with the outside world, causing detrimental effects for the physical and mental development of the students. This study investigates the possibility of improving the design of usually neglected and underexploited outdoor and semi-outdoor spaces within urban learning environments in order to convert these spaces into microclimatic modifiers and natural air filters. The study was based on field work, analytic work and design studies on a case study project for a secondary school in a high density site in London. This is a collaborative thesis project conducted with a London based architectural practice, who shared our interest in the environmental potential of outdoor and semi-outdoor spaces within schools. The research focused on the integration of green spaces into three different environments: outdoor courtyard, semi-outdoor break-out space and indoor classroom. It is later explored how the connection between those typologies effect the air pollution levels, natural ventilation potential and thermal and visual comfort of the occupants. The findings of the analysis and design implementations indicate that the positive microclimatic effect of the green courtyard can be successfully used to achieve thermal comfort in semi-outdoor and indoor spaces throughout the year while improving visual comfort and air quality. The outcome is a guideline based on the post processing of the findings from all the stages of this research. It is aiming to help designers take better-informed design decisions in response to current challenges that UK's urban schools are facing.

**Keywords:** green school, pollution, vegetation, mitigation, urban heat island

## **Introduction**

### ***Research Topic***

According to the UN, 66% of the world's population is projected to be urban by 2050 (United Nations, 2014). This tendency has a detrimental effect on the sufficient contact with natural outdoor environment for urban residents. Being one of the most essential needs for the wellbeing of every human, it has a particularly significant impact on physical and physiological health and correct development of children (Louv, 2008). Various behavioural research about children, youth development and productivity points out the need for connection with nature as essential for the healthy development of young people (Charles, 2015). For decades many individuals worked to bring urban children back to nature. However, it is the current climate-change and information age that brought more awareness to the disadvantages of children's disconnection with nature on their learning abilities (Charles, 2015). This tendency is merely visible in the architecture of educational buildings in the rapidly growing centres of UK cities. Considering that school children spend majority of their daytime hours at schools, this brings a new obligation to urban educational facilities to provide children with a necessary and sufficient contact with the outdoor environment. Nevertheless, such endeavour has many constraints that needs to be taken into consideration. Due to the urbanisation, schools in the cities suffer from lack of space, bad air quality, noise and the consequences of the Urban Heat Island effect, which

compromise their ability to provide quality external space and leads to design of “sealed mechanically ventilated boxes”.

All those factors could be mitigated by conscious use of geometry and urban vegetation. Therefore, this research strives to prove how having green courtyards in centrally-located schools contribute to children’s health and well-being by improving the air quality and thermal and visual comfort. This points to the fundamental question of this research of how the usually neglected outdoor and semi-outdoor areas of urban schools can be used as urban microclimate modifiers and air filters by providing a better quality outdoor learning environment.

## Methodology

This study presents an innovative architectural design approach responding to the negative impact of the Urban Heat Island effect occurring in London. The approach named “Green Pockets” is a localized positive microclimatic strategy based on the creation of natural air-filters and mitigation of outdoor temperatures by implementing greenery in the form of bigger and smaller architectural interventions. It provides the analytical study of three theoretical scales of intervention: MEGA in form of “green pocket” courtyard, MIDI as “green pocket” break-out space and MICRO of “green pocket” classroom, with strong emphasis on the integration and interrelationship of all three stages. All of the three stages are inseparable from each-other and provide a feedback loop thanks to which it can work successfully. Therefore, it proposes the new inverted approach of designing schools in strict urban environments, where the outdoor spaces become an informing factor of the design, rather than being overlooked as it often happens in current practices.

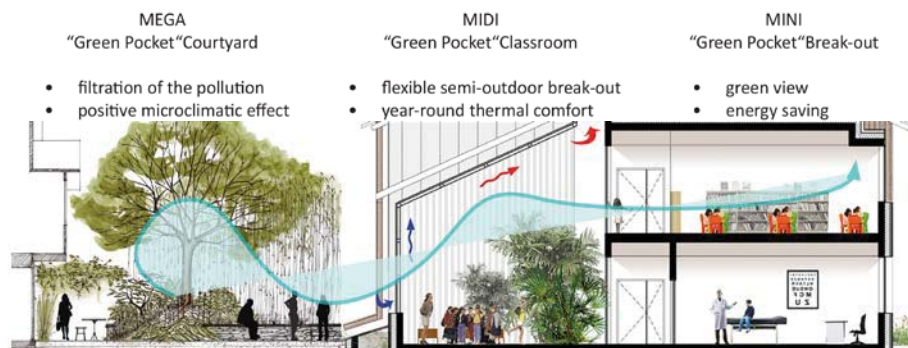


Figure 1. Green Courtyard Concept Section

In the first stage of the macro scale, the “Green Pocket” Courtyard is proposed. The purpose of the courtyard is to provide a secure outdoor space for students, which would work as an air-filter and temperature-regulator. In order to establish the further analytic steps, the courtyard shape was chosen as a base environment. This is due to the typology of the schools built in the UK and Europe and the significance of this form for the schools’ function due to its protective and overlooked properties (Rigolon, 2010). Further, the exemplary courtyard scenarios are investigated in the holistic environmental modelling tool Envi-met (Fig.6) to understand the impact of the different types of vegetation in different orientation on the temperature and pollutant dispersion. Next, those theoretical findings are tested in the base case design to create the profile of temperature change due to the geometry and vegetation design improvements.

In the second stage of midi scale the “Green Pocket” Break-Out space is proposed. This is to provide a thermally comfortable and flexible semi-outdoor environment

throughout the year, especially when the outdoor temperatures do not allow for comfort outside, which occurs during the biggest part of the year in London. To achieve that, dynamic thermal modelling and simulation analysis using the software TAS (Fig.10,11) is undertaken considering the temperature profile from the previous stage.

In the third stage of micro scale the “Green Pocket” Classroom is considered. The main objective of this stage is to understand the possibility for natural ventilation of the classroom using the environment from two previous stages. This analysis is also performed using dynamic thermal simulation. Additionally, the visual benefits of greenery are considered as well as the virtual sky component to ensure that optimal daylight levels are not being obstructed by vegetation.

The findings of this study aim to help the designers to take better-informed design decisions in response to current challenges that UK’s urban schools are facing.

### **Industry Collaboration**

In the light of a vast existing research concerned with the indoors of educational facilities, this research strives to contribute to a more overlooked area of outdoor learning environments in the UK. This interest is shared with the London based architectural practice, Architype Architects, and lead to the formation of the collaboration. The research is based on the theoretical studies and analytical work of general scenarios as well as a specific site currently developed by the practice. However, as both were progressing in parallel, this thesis takes into consideration only a snapshot in time of the proposal before the final stage.

## **Context**

### **Climate**

London’s climate is characterised by its location on 51°N latitude and its mild oceanic climate, due to the Gulf-stream - a warm current in the Atlantic. The current temperatures in London stay below the indoor comfort zone most of the year ranging between 7°C and 19°C. However, due to the increasingly common extreme weather events of heat waves, the daytime temperatures can reach over 30° C. According to ASHREA, comfort band can be only achieved from June to August in the between morning and early afternoon (Fig.2).

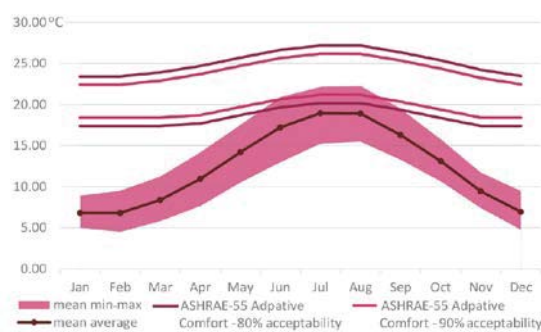


Figure 2. London Mean Average Temp. and ASHRAE-55 Comfort Band (Meteonorm v.7)

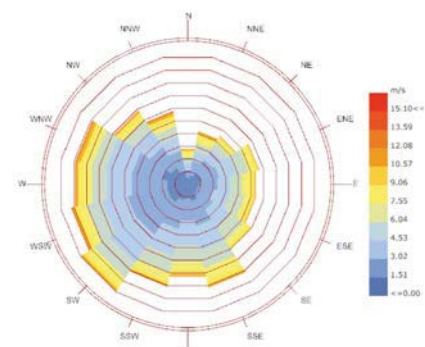


Figure 3. London Wind Rose (Meteonorm v.7 + Ladybug for Grasshopper, Rhino)

### **Urban growth and Urban Heat Island effect**

London is predicted to reach 10 million citizens by 2024 and 13 million by 2050 (Dearden, 2016), which will qualify it as a megacity, that usually refers to a metropolitan area with a

population of more than a 10 million people. This strong pressure results in the need for urban schools to accommodate as many students as possible while simultaneously being allocated on insufficient plots due to the intense urbanisation. Therefore, it is very common in London that the schools sites are not appropriate and classify as compromised so they do not have to reach guidelines of minimum outdoor areas.

A very challenging implication of urbanisation is the warming of local climate in comparison to adjacent rural surroundings, commonly known as the Urban Heat Island effect (Susca, Gaffin and Dell’Osso, 2011). The intensity of this phenomenon differs across the city but may reach 9 °C in the UK. In cities like London it occurs in a dense urban centre but also in scattered smaller “high risk pockets”. Contributing factors include the thermal properties as well as the type of the cover and albedo of the materials and ground coverage, height and spacing of the buildings, air pollution and waste heat. The local microclimate change and extreme weather events (heat waves) caused by UHI are responsible for around 1100 premature deaths per year in UK. This is especially dangerous for vulnerable individuals like children. “Urban planning, building design and landscaping can all provide strategies for mitigating the UHI. Vegetation has a key role to play in contributing to the overall temperature regulation of cities. Informed selection and strategic placement of trees and green infrastructure can reduce the UHI and cool the air by between 2 °C and 8 °C, reducing heat-related stress and premature human deaths.” (Doick, K. and Hutchings, T., 2013). The increase of natural elements, vegetation, and trees in particular, can be extremely effective in mitigating the UHI because it offers different cooling mechanisms working simultaneously, including evaporative cooling, transpiration, reflectance of solar radiation by change of albedo and providing shade (Doick, K. and Hutchings, T., 2013).

### **Pollution**

London’s pollution levels in January 2017 surpassed Beijing’s readings peaking 197 micrograms per cubic metre for particulate matter (Knapton, 2017). The common PM level in developing cities oscillate around 70 µg/m<sup>3</sup> – almost three times less than recent London reading. Moreover, the World Health Organisation recommends decreasing it even further to 20 µg/m<sup>3</sup> which would reduce the air-pollution related deaths by 15% (WHO, 2016). “London’s filthy air is a health crisis and the children are particularly vulnerable to the toxic effects of air pollution”. As a consequence, Mayor of London encourages urban schools to reposition the entrances and playgrounds away from the busy streets. Admittedly, he recognises the potential for natural elements as a solution and persuades schools “to plant hedges and bushes around their sites as barriers to block out the fumes.” (Knapton, 2017).

The vegetation in urban environment influences the pollution levels based on two processes - deposition and dispersion. Deposition describes the process of the airborne particles of pollution being attached to the surfaces while passing close-by. As plants usually have large surface areas per its volume, thus the possibility of deposition is increased 10-13 times in comparison to smooth manufactured surfaces like glass or concrete. The second process of dispersion, in simple, refers to the porosity of the vegetation, therefore to the effect of the surface texture on the wind field (Janhall. 2015). Both of these processes result in the pollution particles being stored on the tree surface and removed from the air that can be potentially channelled to the “cleaner air” area. Hence, theoretically the removal of the pollution molecules from the air is mostly related to the trees’ geometry and could be supplemented by man-made structures resembling vegetation. However, another way plants help with pollution levels is by photosynthesis, known as the process of conversion of



carbon dioxide to oxygen. Additionally, the microbes within the roots of the plants have ability to covert the toxins into nutrients, which cannot be recreated.

### **Noise**

Another implication of the heavy road transport and domestic and commercial heating systems is noise pollution, which can not only negatively affect the focus and attention of students but can even preclude the lessons itself or the external areas used as formal and informal learning and recreation environments 60 dB is consider an upper limit. Achieving that is possible in the surroundings where noise level is as high as 70 dB (Institute of Acoustics, 2015). In proximity of busy central London streets in some cases the noise level can easily surpass 80 dB. Therefore apart from the initiatives to mitigate noise pollution in the outdoor areas, sometimes it is crucial to create an intermediate, more enclosed zones that could allow for the control of the noise levels.

### **Field Work**

The field work conducted for this study is aimed to look deeper into the challenges that schools located in central areas of London are currently facing. This includes the different phases of research from interviews and spot measurements to continuous monitoring. The first aim of this field work is to understand the needs of the urban students. Secondly the microclimatic studies focus on exploring the performance of outdoor areas in urban schools with emphasis on the selection of problems understood from the interviews phase. Both case studies - Chelsea Academy and St Michaels Catholic College - were carefully chosen based on their location and curriculum. Both schools are located in the central part of London, in medium to high density setting and in proximity to the busy roads and operate throughout the whole year beyond the general school hours. Moreover, the site they are situated at required a creative approach to placement of the outdoor areas, using rooftops and courtyards arranged on the limited space.

The outdoor areas of the school are of great importance and are used as main break-out spaces. However, both schools suffer from insufficient space and lack of adaptive outdoor opportunities and semi-outdoor spaces that would extend the usability of outdoor spaces. In both cases the sheltered outdoor spaces showed the ability to mitigate the temperature changes. This has a big potential that can be used in the planning of new designs. This is of great importance especially because all physical education classes are organised outdoors with the potential of other classes expand to outdoor environment if well designed.

Considering London's moderate climate and warming of night temperature due to UHI it is possible to add extra semi-outdoor areas that would protect from weather condition like sever radiation or precipitation, which could increase the amount of times learning activities take place outside.

The field work confirmed the strong disconnection between the users and the building ventilation strategy. In both cases, users were not fully aware of the systems implemented. Therefore, many potential drawbacks occurred. The window being open while the ventilation is operating throughout summer can potentially cause high energy consumption and increase the carbon footprint of the building. This was especially visible in comparison to the mechanically and naturally ventilated classrooms. The unchangeable set-point can cause classrooms to overheat when activities performed become more intense while the overall temperatures of naturally ventilated classroom were more often in comfort (Fig.4).

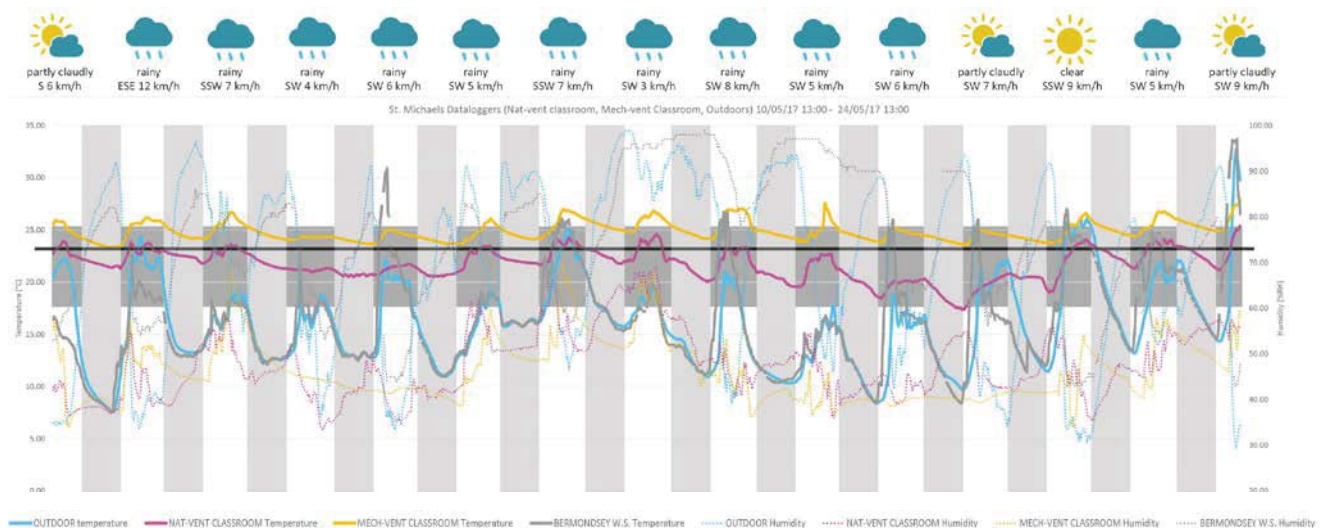


Figure 4. St. Michael's Catholic Collage temperature and humidity levels from 10/05/17 to 24/05/17

## Analytic Work

### MEGA "Green Pocket" Courtyard

Air pollution is the biggest enemy of natural ventilation. Several assumptions can be made to assure local improvement of the air quality in comparison to the nearby streets. As on the site, on which this research is based on, the prevailing wind direction and main source of pollution (nearby heavy traffic road) are aligned it is too fortunate arrangement to be used in a simplified simulation to investigate the consequences of design intervention to work against the pollution in the building scale. Therefore, the investigation of other theoretical courtyard arrangements and orientations in regards to the pollution source was adopted.

Firstly, the theoretical model of different courtyard variations with and without vegetation is modelled in Envi-met to confirm the assumptions based on the literature. The physical barrier of geometry between the source of pollution and outdoor space can stop the unwanted air from mixing with the cleaner air of the courtyard. This can be achieved by following the skimming movement dimensions rule from the CIBSE Guide A of the distance between the buildings oscillating between 1 and 1.4 times the buildings' height (CIBSE, 2015). It is beneficial to consider that arrangement if the wind direction is parallel to the axis between the source of pollution and the courtyard. However, it is crucial for air consisting the pollution particles to be further diluted with the cleaner air. Therefore it would be of the highest priority to strive for a geometrical arrangement closed in the proximity of the main pollution source but open to the sites with wind coming from the different direction.

Implementation of the tall and dense trees in constrained courtyard is not beneficial as arrangement like this cause the pollution particles to be trapped inside due to low internal velocity (Fig. 6). Therefore, it is recommended to introduce smaller forms of vegetation, or increase the area of the courtyard. Moreover, the stagnation of the pollution is partially caused by its density. As air density ( $1.20\text{g/cm}^3$ ) is smaller than the pollutants densities ( $\text{NO}_2$ :  $1.45\text{g/cm}^3$ ;  $\text{PM}_{2.5}$ :  $1.60\text{g/cm}^3$ ;  $\text{PM}_{10}$ :  $1.60\text{g/cm}^3$ ) without the wind driven air moment, it is difficult to remove them from the confined space. However, this could be achieved by inducing the air movement in the vertical axis, for example by increasing the buoyancy or decreasing the density of the air. This could be achieved by improving the humidity levels in the courtyards as air density is higher than water density ( $1.00\text{g/cm}^3$ ).

As shown in the simulation (Fig. 6) and in the literature the deposition effect of the vegetation is most successful in the proximity of the source. Nevertheless it is not very useful to block the air from entering the area that is a subject to purification. Therefore the double barrier could be implemented with the trees close the source of pollution, buffer area and the solid structure to limit the air from entering the courtyard. The vegetation needs to be high enough to remove and disperse the pollution as much as possible as well as dense enough to provide deposition but not too dense to block it.

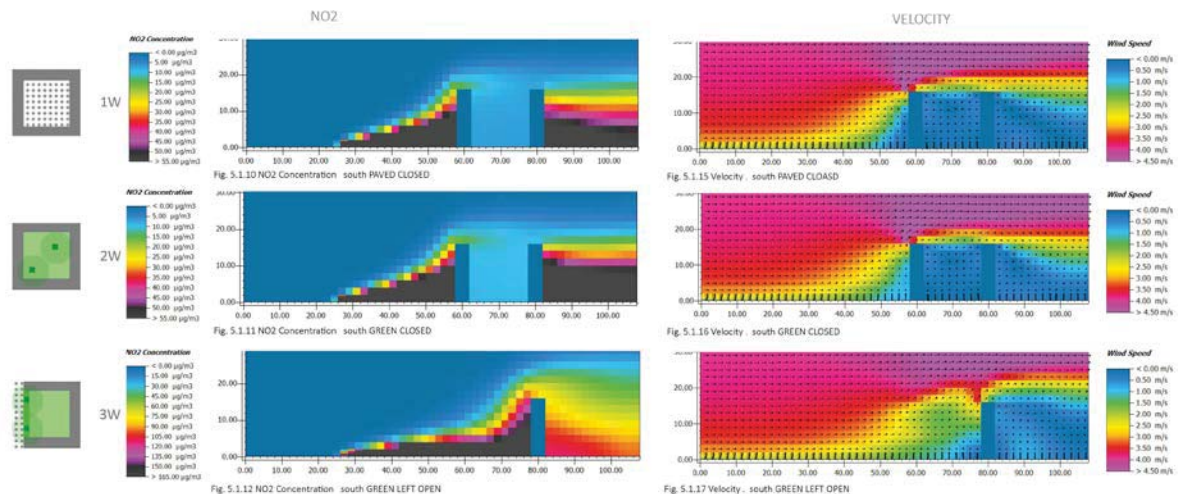


Figure 6. Relationship of NO2 concentration and wind velocity in chosen courtyard arrangements (Envi-met)

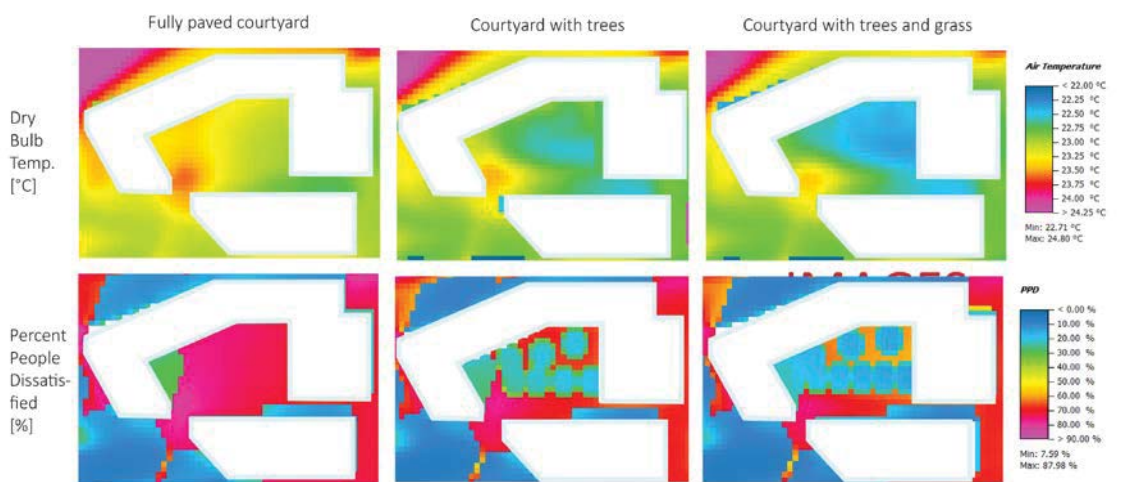


Figure 7. Comparison of different types of greenery in the courtyard on average summer day (Envi-met)

The further investigation of MEGA “Green Pocket” Courtyard is based on the aforementioned theoretical phase of the pollution study with the assumption that introduced massing and greenery is successfully able to provide a decrease in pollution levels in the courtyard itself by blocking the pollution source and filtration through vegetation.

Therefore, the first type of simulations on the base case model (Figure 7) is performed in order to understand changes of the dry bulb temperature, mean radiant temperature, wind velocity and therefore the thermal comfort based on Predicted Percentage Dissatisfied (PPD) method that are the consequence of different courtyard modifications: paved surface, trees, trees and grass. It can be observed that the majority of change happens between the



paved courtyard variation and the variation with trees only. The addition of grass has proportionally smaller impact. Nevertheless, the best results can be achieved by combining the two strategies.

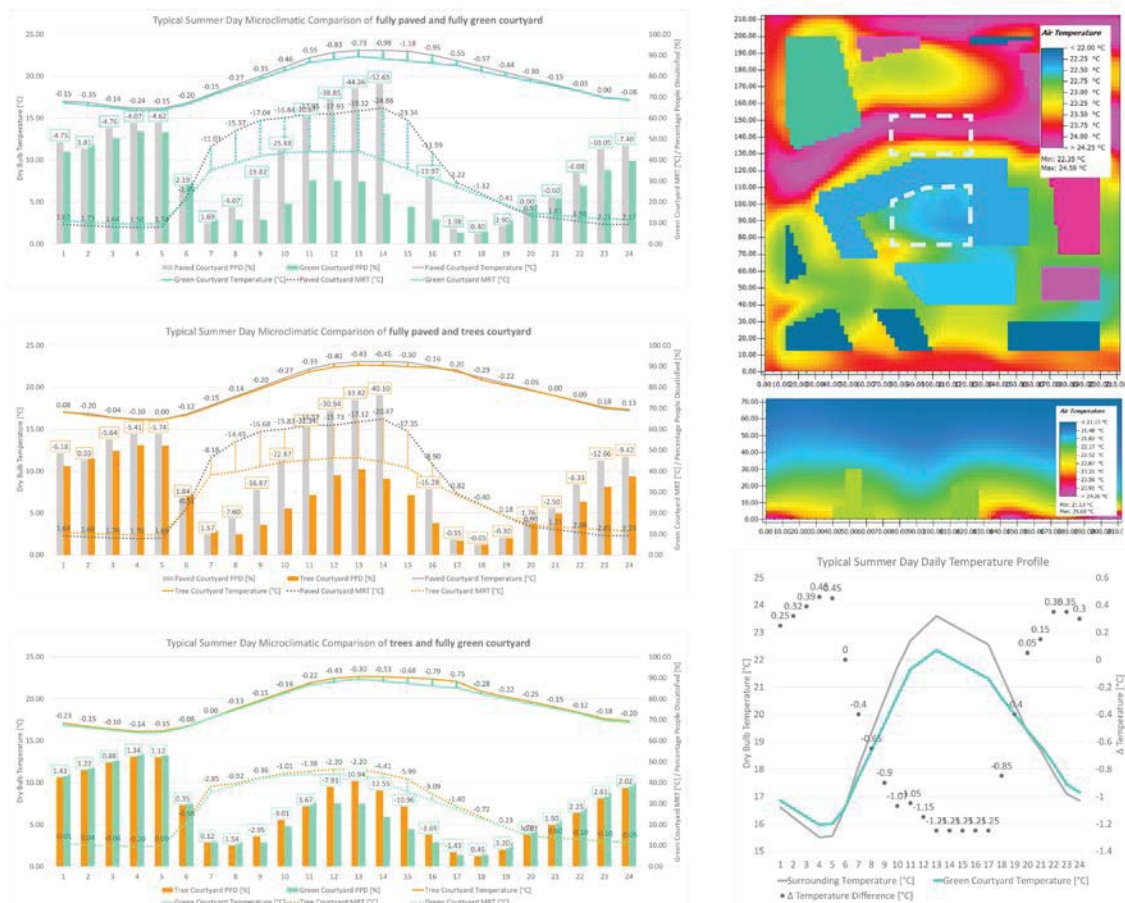


Figure 8. Positive microclimatic effect of the courtyard – average summer day (Meteonorm + Envi-met)

The second type of the simulation (Fig. 8) combines the effect of the geometry with the most successful scenario of green courtyard (with grass and trees) and compare its conditions to the adjacent temperatures of the site. This way the temperature change profile is created that is used in the further stages of the research (Fig. 9). The observation of the changing condition in the courtyard indicated that the positive microclimatic effect of the sheltered courtyard is noticeable during the entire year. The time the temperature is shifting however, changes and it can be assumed it is based on daylight hours as shortens respectfully of the sun-path in different months. In summer, the courtyard with trees and grass benefits from higher temperature mitigation and lowest PPD ratings. However, during the colder months of winter season, the trees obstruct to some extent the desirable solar radiation, thus affecting the Mean Radiant Temperature and decreasing thermal comfort levels.

### MIDI “Green Pocket” Break-Out

The critical value of the semi-open and flexible opportunities was one of the most echoing findings of the field works in London urban schools. The MIDI “Green Pocket” Break-Out Phase of the research aims to create a flexible semi-outdoor space that could be providing an outdoor-like experience with a whole year-round thermal comfort conditions. This phase

of the research is based on findings of mitigated temperature and reduced pollution levels from the “Green Pocket” Courtyard phase.

Typical Summer Day Daily Temperature Change Profile																								
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
ΔT	0.25	0.32	0.39	0.46	0.45	0	-0.4	-0.65	-0.9	-1.07	-1.09	-1.13	-1.25	-1.25	-1.25	-1.25	-1.25	-1.25	-1.25	-1.25	-1.25	-1.25	-1.25	-1.25

Typical Mid Season Day Daily Temperature Change Profile																								
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
ΔT	-0.27	-0.26	-0.27	-0.27	-0.24	-0.23	-0.2	-0.09	0.08	0.13	0.19	0.22	0.19	0.1	-0.01	0	-0.09	-0.28	-0.28	-0.28	-0.27	-0.31	-0.29	-0.29

Hot Summer Day Daily Temperature Change Profile																								
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
ΔT	1.44	1.18	0.92	0.68	0.83	0.37	0.1	-0.05	-0.67	-0.51	-0.34	-0.84	-0.97	-1.2	-1.38	-1.4	-1.35	-1.18	-0.6	-0.27	-0.02	0.23	0.3	0.37

Typical Winter Day Daily Temperature Change Profile																								
Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
ΔT	-0.15	-0.05	0.2	0.38	0.2	0.12	0.11	0.12	0.1	-0.05	-0.18	-0.18	-0.35	-0.31	-0.24	-0.21	-0.08	-0.16	-0.1	-0.1	0.05	-0.29	-0.12	-0.12

Figure 9. The temperature change profile (data from Envi-met simulation)

The research starts with the summer scenario as it is more challenging than the winter scenario, where the sufficient internal gains provided by the occupancy and low energy/passive standard materials supported by heating system are more probable to provide indoor thermal comfort levels.

The dynamic thermal simulation studies in TAS on the base case geometry proved that with integrated utilization of outdoor courtyard temperatures mitigation it is possible to achieve the semi-outdoor flexible space that would be thermally comfortable throughout the whole year and during extreme weather events.

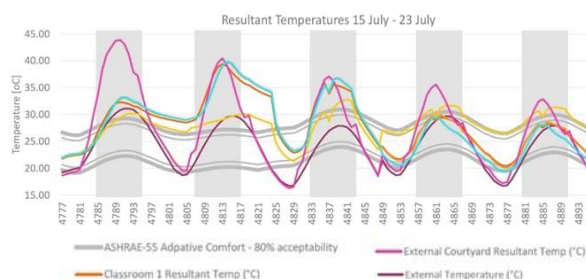


Figure 10. Base case scenario resultant temp. (TAS)

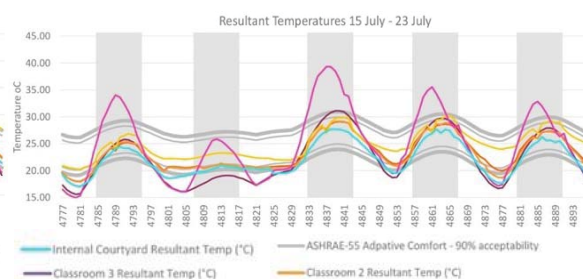


Figure 11. Final case scenario resultant temp. (TAS)

The results of the research from the previous chapter allowed to consider the courtyard air to be decreased in pollution content and therefore suitable to be used for natural ventilation. With this conclusion in mind the naturally ventilated scenarios performed as good as or better than the mechanically ventilated ones, confirming the finding of literature review and field work in urban schools.

The limitation of insufficient literature regarding the effect or benefits of the indoor plants on the thermal comfort during the colder periods had to be committed. Therefore, it would be beneficial if further research could cover this in more detail.

### **MINI “Green Pocket” Classroom**

Considering the number of school buildings currently build in London under the fact that most of them are designed as mechanically ventilated with no openable windows and adaptive opportunities and the strong disconnection observed between the users and operating system, it can be assumed that there is a vast potential in reducing the energy consumption by implementing the natural ventilation strategies. However, the sky-rocketing levels of pollution and noise in central London being the main drawback of natural ventilation strategies in urban schools, this research proves the wide scope for building scale integrating strategies that could help with creating local pockets of air filtering.



The integrated approach of feedback between the MEGA “Green Pocket” Courtyard, MIDI “Green Pocket” Break-Out and MINI “Green Pocket” Classroom results in providing whole-year round thermally comfortable classroom environments (Fig 11) complying with the Building Bulletin 101 on Guidelines on ventilation, thermal comfort and indoor air quality in schools (Fig 12).

The cooling and heating loads of the basic case and the final case are then compared in order to understand the potential savings achieved by introducing natural ventilation, small architectural interventions (like shading and buffer zone) and mitigated effect of green courtyard.

The values presented in the Figure 13 in kW/m<sup>2</sup> represent the comparison values of different set-points for heating and cooling loads calculated as an average for typical classroom in the design.

In the maximum cooling period between 1st April and 30th September, the final scenario required no cooling while the basic case could need 15kW/m<sup>2</sup>. According to ASHRAE 55 thermal comfort band maximum acceptable temperature is 29 °C. However due to the very sporadic frequency of this temperature occurring in UK climate, it is understood that the cost and embodied energy of cooling system would not be cost-effective as it can be easily achieved with well-designed natural ventilation.

In the maximum heating period between 30th September and 1st April the heating of school spaces is almost unavoidable even when passive strategies are used. Although the occupancy is more intense, on average 30 people in classroom, it is also more sporadic. Moreover the activities occurring in dwelling that contribute to internal gains, like cooking or electrical equipment, are not present. Additionally, there are less adaptive opportunities related to clothing value (clo) due to the clothing guidelines for students and mandatory dress-code. The minimum temperatures in the classrooms depend on the activities performed: “18°C in areas of normal level of physical activity associated with teaching (i.e. ordinary classrooms), 21°C for lower than normal activity (e.g. sick rooms) and 15°C for higher than normal activity (e.g. gymnasias, washrooms)” (Middlesbrough Division 1999).

Therefore, for secondary schools three different set-points were considered at 18°C, 19°C and 20°C. As can be seen in Fig 13 the heating loads of base case are significantly higher than the final case. Especially the variant with intermediate buffer zone achieve only 1kW/m<sup>2</sup>/year more heating and cooling load combined than the passive house standard. This value can be compared to TM46 CIBSE Energy Benchmarks (Department of Education, 2016) to notice that the best case scenario requiring 16kW/m<sup>2</sup> energy use for heating and ventilation (Fig. 13) is over 3 times lower than the standard for UK of 51 kW/m<sup>2</sup> for electrical heating with natural ventilation in secondary schools (Fig. 12).

Table 6 Distribution of energy use by internal environment

Internal environment	Primary			Secondary		
	N	Electricity	Fossil-thermal	N	Electricity	Fossil-thermal
		EUI	EUI		EUI	EUI
		Median (kWh/m <sup>2</sup> )			Median (kWh/m <sup>2</sup> )	
Natural ventilation only	4	48	147	-	-	-
Heating and natural ventilation	6396	43	122	914	51	122
Mixed-mode with natural ventilation	114	48	119	57	53	122
Mixed-mode with mechanical ventilation	21	50	106	9	66	95
Heating and mechanical ventilation	140	50	118	48	57	112
Air-conditioning	11	47	99	7	49	97

Note: EUI = energy use intensity

Figure 12. Schools heating and cooling benchmark (TM46)

	Cooling	Heating 18C	Heating 19C	Heating 20C
Basic Design	15.4	105.44	155	182
Improved Design (without glazed buffer)	0	25	30	35
Improved Design (with glazed buffer)	n/a	16	20	25

Figure 13. Achieved heating/cooling loads (TAS)

The importance of children connecting with the natural environment, commonly described in psychological research, is rarely visible in the design of contemporary urban schools in London. The vegetation expresses rather decorative and meaningless characteristic in regards to its choice, placement and function. The psychological benefits on mental health of children in secondary school age cannot be overlooked especially based on its impact on learning capabilities. Tension relief, calming factor, increase in cooperative behaviour, integration can prove greenery to be used almost as a form of therapy especially for challenging urban youth exposed to a more stressful life than their peers in the countryside. Additionally, many potential benefits of vegetation in outdoor and semi-outdoor learning environments proven above it can be also used indoors as a visual reference. Several studies indicate the beneficial effects of even the green view during the teaching time. The study by Yu et al, 2016 introduce the new method of quantifying the green view. The Floor Green View Index is described as an area of visible urban vegetation from certain point of the room floor in urban building. Taking into consideration green distribution, building and floor height and proximate context in order to map a facade of potential geometry in gradient based on the percentage of FGVI. Implementing the greenery in the final case design does not impact the SVF and proves to allow sufficient daylight in the classroom while providing additional green view benefits (Fig 14, Fig 15).

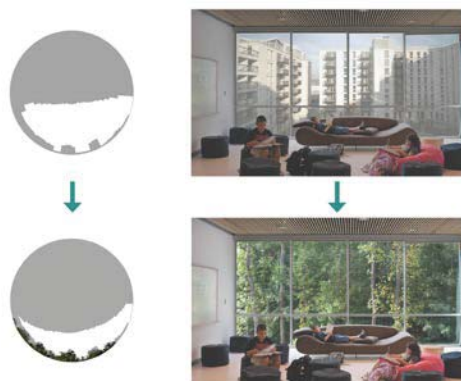


Figure 14. SVF for base and final scenarios (Lady-bug, Rhino)

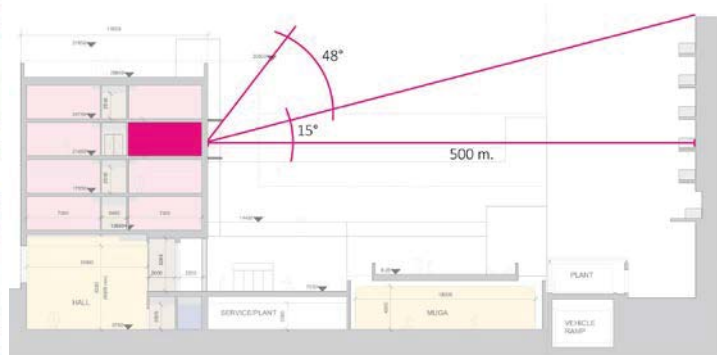


Figure 15. Obstruction angles providing a sufficient daylight factor

## Conclusion

The research presented the theoretical background and analytical approach to designing outdoor green areas of schools in central urban locations.

The theoretical modelling of courtyards and pollution sources showed that the solid walls are incomparably better barriers than green walls however they do not filter the pollution at all. Moreover the orientation did not matter as much as the direction of the wind and pollution source position. Therefore, this two types or barriers should not be compared and rather use complimentary based on the design intention.

The “Green Pocket” concept of three integrated green environments -courtyard, break-out and classroom - proved to work according to the assumptions. The courtyard’s microclimatic effect created a temperature profile of filtrated air that was further introduced in the semi-outdoor and indoor stage. The integrated approach resulted in lower outdoor daytime temperatures, and slightly higher night time temperatures in the courtyard as well as flexible semi-outdoor and indoor areas of comfortable resultant temperatures

and only 16 kWh/m<sup>2</sup> of heating and cooling loads per year. This is a methodology that could be applied to other educational facilities.

Taking into account that educational facilities are one of the most numerous typologies that can be found in the strict centre of London, any size of intervention that could be implemented and connected to the adjacent “Green Pockets” could contribute to the creation of a city-scale feedback loop of positive microclimatic effect. Therefore, although one building is not able to reverse the warming or clean the pollution of entire city the integrated unlimited number of “Green Pocket” opportunities could become a urban strategy working simultaneously from the bottom up and from up to the bottom bringing London to the de-carbonation pledged during Paris summit.

## References

- CIBSE (2016) Guide A Available from: <http://www.cibse.org/knowledge/knowledge-items/detail?id=a0q2000008I79JAAS> [Accessed 20 April 2017].
- Charles, Ch. (2015). Children’s contact with the outdoors and nature: a focus on educators and educational settings. Available from: <https://www.childrenandnature.org/wp-content/uploads/2015/04/EducationsynthesisMarch2010FINAL.pdf> [Accessed 20 April 2017].
- Children and Nature Network. (2016). Tools & Resources. Available from: <http://www.childrenandnature.org/learn/tools-resources/> [Accessed 20 April 2017].
- Department of Education. (1991) Building Bulletin 71 – The Outdoor Classroom. Available from: <http://science.cleapss.org.uk/resource/DFEE-Buildin-Bulletin-71.pdf> [Accessed 20 April 2017]
- Department of Education. (2016) Building Bulletin 101 - Guidelines on ventilation, thermal comfort and indoor air quality in schools Available from: <http://bit.ly/2mDP7bC> [Accessed 20 April 2017]
- Dearden L. (2016) London population predicted to near 10 million within a decade as England continues to grow Available from: <https://ind.pn/1sPTsqP> [Accessed 20 April 2017]
- Doick, K. and Hutchings, T. (2013) Air temperature regulation by urban trees and green infrastructure Available from [https://www.forestry.gov.uk/pdf/FCRN012.pdf/\\$file/FCRN012.pdf](https://www.forestry.gov.uk/pdf/FCRN012.pdf/$file/FCRN012.pdf) [Accessed 19 March 2017].
- Erell E. (2011) Urban Microclimate, Designing the Spaces Between Buildings. Washington USA: Earthscan; 2011
- Institute of Acoustics. (2015) Acoustics of Schools: a design guide Available from: <http://bit.ly/2fOZ2Ti> [Accessed 19 March 2017].
- Janhall S. (2015) Review on urban vegetation and particle air pollution - Deposition and dispersion Available from: <http://www.sciencedirect.com/science/article/pii/S1352231015000758> [Accessed 19 March 2017].
- Knapton, S. (2017) Air pollution in London passes levels in Beijing. Available from: <http://www.telegraph.co.uk/science/2017/01/24/air-pollution-london-passes-levels-beijingand-wood-burners-making/> [Accessed 19 March 2017].
- Mayor of London. (2017) Health and Exposure to Pollution. Available from: <https://www.london.gov.uk/what-we-do/environment/pollution-and-air-quality/health-and-exposure-pollution> [Accessed 19 March 2017].
- Middlesbrough Division (1999) Available from <http://www.middlesbrough-nut.org.uk/temperat.htm> <http://www.middlesbrough-nut.org.uk/temperat.htm> [Accessed 19 March 2017].
- Rigolon R. (2010) European design types for 21st century schools: an overview Available from: <http://www.oecd.org/education/innovation-education/centreforeffectivelearningenvironmentscele/44708431.pdf> [Accessed 20 April 2017]
- Susca, T., Gaffin, S.R. and Dell’Osso, G.R. (2011) Experimental Study of the Thermal Performance of Living Walls Under Semiarid Climatic Conditions Available from: <http://www.sciencedirect.com/science/article/pii/S1876610215028246> [Accessed 19 March 2017]
- United States Environmental Protection Agenc. (2016). Using Trees and Vegetation to Reduce Heat Islands Available from: <https://www.epa.gov/heat-islands/using-trees-and-vegetation-reduce-heat-islands> [Accessed 19 March 2017].
- Yu et al. (2016) View-based greenery: A three-dimensional assessment of city buildings’ green visibility using Floor Green View Index Available from: <http://www.sciencedirect.com/science/article/pii/S0169204616300329> [Accessed 19 March 2017].

# An Overview of the Competition Projects in Architecture Coded with Sustainability Criteria: The Case of International High-rise Award 2014/2015

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**Abstract:** One of the public issues regarding the skyscraper and urban relation that have gained importance in the world scale in recent years has produced popular concepts such as sustainability, ecological and green architecture. As seen in many of the developing world cities, when looking at vertical dense building projects using ecological data in the context of sustainability, they cannot go beyond superficial interventions in which several energy-saving technologies are installed in the structure and placed in some intermediate spaces of the green building. It is clearly seen that the image of ecological high-rise buildings is symbolized through various signs such as sustainability certificates and green architecture discourses. On the other hand, in terms of developed world cities, sustainability and ecological architecture become an important issue, and architectural practice is making considerable progress in this direction. International high-rise building awards are not only concerned with the matters such as architectural image, form or height claim, but also how much high-rise buildings are concerned with ecological data and environmental awareness. The paper aims to discuss the quality of competition projects in architecture encoded with sustainability criteria on the case of International High-rise Award in 2014/2015. There are five finalist projects, Bosco Verticale in Milan-Italy, Fira Hotel in Barcelona-Spain, De Rotterdam office in Rotterdam-Netherlands, Sliced Porosity Block in Chengdu-China, One Central Park in Sydney-Australia, selected in the scope of the research analysed through the signs of sustainability showing how the criteria of sustainability design is described in the process of architectural competitions. In terms of high-rise buildings, the provision and the encouragement of ecological life principles is considered as one of the main issues. These projects show that the sustainability issue is not only regard to building scale, but also, with holistic design criteria, it needs to be addressed at urban scale.

**Keywords:** Architectural competitions, ecological architecture, high-rises, signs of sustainability, urban design.

## Introduction

The rapid and non-infrastructure urbanization process that accompanies the development of technology and population growth because of the Industrial Revolution led to the rapid depletion of natural resources and major problems in the physical and biological environment. The inadequacy of urban land by urbanization and consequently the excessive increase of land prices caused to vertical building construction. There are many other factors caused to move towards high-rise structure besides the increase of land price. The advances in material, construction and design technology, the growth of economy, the need of built monumental structures symbolizing the power of large companies, the use of high-rise structures as a political investment instrument with the globalization process led to shift on the image of world cities. The new economic dynamics, global service, increase of financial service functions and specialized services have significant effects on the form of urban space. The transformation of lifestyles and consumption patterns results in spatial change (Baba, 2012). The increase in luxury housing construction, new office and residential towers reflecting high-quality of life are some of the signs of this change. Global architectural trends are based on the desire to create flashy buildings and city icons that reflect the power of the client and the investor. With the desire of creating branded cities, high-rise structures are used as an image and symbol of power and demonstration than need (Short, 2007; Wood, 2011). In different regions of the world, the world cities display different symbols of high-rise buildings. Many of these buildings are aiming to create ecological skyscrapers that reflect sustainable, ecological design principles, while exhibiting splendid designs and forms on the one hand.

Considering the relationship between skyscraper and urban design, popular concepts such as sustainability, ecological and green architecture stand out as one of the public issues that gained importance in world scale in recent years. The high-rise buildings consuming much more energy than the low-rise buildings in the phases of design, construction, use and demolition led to significant changes in the city skyline with increasing numbers. In this context, the concept of sustainability is of great importance to benefit from high-rise structures efficiently and to minimize the harm to the natural environment. Ecological skyscraper, while emerging as a growing awareness to reduce negative impacts of high-rise buildings on the environment, is used as an effective architectural image to give the residents the “natural environment” and a more “sustainable” structure image in the urban fabric.

In most of the developing world cities, sustainable and ecological high-rise projects are defined by superficial interventions where several energy-saving technologies are integrated into the building and placed in some intermediate spaces of the green building. In respect to the interest of eco urban architecture worldwide, ecological vertical building image is commonly symbolized through various signs such as sustainability certificates, green architecture spaces and discourses. The sustainability becomes a challenge for the cities reflecting unplanned urbanization and construction process without infrastructure such as Istanbul, Mumbai, Sao Paolo and Buenos Aires. The high-rise buildings create a hybrid image on urban silhouette due to the chaotic integration of global and local structures. On the other hand, for cities such as Hong Kong, Dubai, Shanghai, New York and Chicago, which are among the top 10 cities in the world scale, the integration of high-rises with urban area is more successful. The high-rise buildings are integrated into the urban space with infrastructure systems around them, connectivity to transport and metro networks, pedestrian and human-oriented walking paths, interspace solutions.

International high-rise building awards are not only concerned with the issues such as architectural image, form or height claim, but also concerned with the level of integration among high-rise building, ecological data and environmental awareness. The aim of the paper is to discuss the quality of competition projects in architecture encoded with sustainability criteria on the case of International High-rise Award between 2014 and 2015. There are five finalist projects, Bosco Verticale in Milan-Italy, Fira Hotel in Barcelona-Spain, De Rotterdam office in Rotterdam-Netherlands, Sliced Porosity Block in Chengdu-China, One Central Park in Sydney-Australia, chosen in the scope of the research and analysed through the signs of sustainability displaying how the criteria of sustainability design is described in the process of architectural competitions. Particularly in high-rise residential buildings, the provision and the encouragement of ecological life principles is regarded as one of the most important subjects. According to the criteria based on the evaluation process of the competition projects, the sustainability is regarded as an issue that should be addressed in urban scale with holistic design principles and not only in building scale.

## **Methodology**

Theoretical ground of the research is shaped with literature studies and evaluations regarding increased use of sustainable design principles in high-rise residential projects. One of the main questions of the study is focused on the effects of sustainability issue, considering the evaluation process of architectural competition projects. The methodology of research is based on qualitative research method basically used in the examination of architectural design studies (Groat & Wang, 2013). The case study deals with qualitative aspects in terms



of formal, functional and behavioural qualities, presenting the outcomes of projects to the environment and urban area.

The content analysis of the five selected projects, consists of descriptive aspects such as location, typology, year of built, architects and the scale of the buildings, as well as the ecological and sustainability criteria used in the process of design. The reports explaining the jury statement about the projects are assessed as the main sources of the case study. In addition to content analysis, the high-rise projects are analysed in the context of some key questions reflecting the attitude to sustainability issue in terms of building and urban scale.

### Sustainability Concepts in High-Rise Building Design

Sustainable architectural principles become prominent to prevent ecological disasters in the future and to create an environment-friendly built environment. Sustainable architectural principles are recorded as biological structure design principles that develop solutions for energy, water and material use, resource management, environmental problems encountered in pre-construction period, construction period and post construction period, life cycle design in buildings, human health and comfort problems. According to Kim & Rigdon (1998) there are three principles of sustainable design: Economy of resources, Life cycle design and Humane design. The diagram summarizes the three concepts and their strategies (Figure 1).

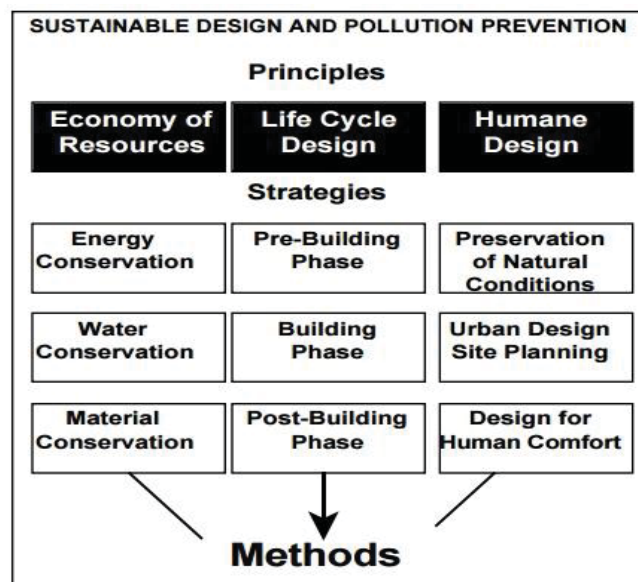


Figure 1. Conceptual framework for Sustainable Design and Pollution Prevention in Architecture (Kim & Rigdon, 1998).

Creating the most accurate solution considering many criteria such as land, mass form, height, orientation according to the factor of climate and landscape, use of floor areas, space organization, façade systems, vertical circulation systems, service systems, is required for the sustainability of high-rise structures. Design and development integrate the existing ecological effects into building design as well as the other bioclimatic aspects: the most efficient use of rain and wind, the life cycle approach to building equipment and material utilization, and the development of interior-life examples for users of high-rise buildings (Al-Kodmany, 2015).

Design and development studies on high-rise buildings has led to the emergence of a new building type called bioclimatic skyscraper in recent years. The design system of this skyscraper is shaped around a concept, which responds to the dynamics of climate, solar

spectrum, wind direction avoiding from the traditional geometry. Environmental factors regarding geographical context and climate context are used both as an energy source and as a design input in high-rise building projects (Hamzah & Yeang, 1994). Providing pedestrian areas for the daylight and shadow, wind effect, protection against weather conditions and the minimum distance between towers for sufficient light, air, access and visibility are among the major environmental factors.

A significant number of construction projects argue that energy efficiency and the use of natural building materials are important in their design in the context of sustainability discourses. Some of them have international green building certifications such as LEED, BREAM, MINERGIE, Green Star, etc. These systems, which bring standards in the framework of sustainability in high-rise buildings, tend to classify buildings in accordance with a number of criteria, from harmony in urban fabric to energy, from interior quality to sustainability of systems, from carbon dioxide emissions to the use of natural resources (Zuo & Zhao, 2014). As one of the indicators of sustainability, these certification systems focus on intelligent building automation systems and sustainable facade technologies, as well as energy, water, material efficiency strategies, use of recyclable or renewable materials, rather than the taken design decisions in the structural form. These certifications, which evaluate the building systems rather than the design decisions, are not incomplete because the designer does not give the necessary information about the building design. According to Jason F. McLennan(2004), sustainable design is described as “a philosophical approach to design that seeks to maximize the quality of the built environment while minimizing or eliminating the negative impact to the environment”. Regionalism emerges as one of the compelling ideas that shape sustainable design described by McLennan (2004). Design responses should change to the different biome and climate conditions. Therefore, sustainability certification systems should be able to present changeable standards to building design according to different countries and environments. Every country should develop their own standards to reach a sustainable environment and building design.

McLennan (2004) also developed six governing principles for sustainable design, respect for the natural systems-the biomimicry principle, respect for people-the human vitality principle, respect for place-the ecosystem principle, respect for the cycle of life-the “seven generations” principle, respect for energy and natural resources-the conservation principle and respect for the design process-the holistic thinking principle are developed. Integrating high-rise buildings into the sustainable city is moving towards an inclusive and holistic approach. In this context; the sustainability of high-rise buildings depends on the strong relationship with the urban infrastructure and environment. Proper urban planning is necessary to enhance social interaction, relationship and participation. The development of high-rise and supertall buildings should contribute to the social life and the vitality of the city without being isolated from the surroundings (Firley & Gimbal, 2011). Unfortunately, there are many instances in which high buildings have been isolated from the surrounding neighbourhoods and city life as closed settlements. In this context, the challenges related to the urban integration process of high-rise buildings are emerging as major problems in the sustainability issue.

Ghertner (2011) states that green aesthetic understanding is limited to a general assessment regarding how a city should appear in dominant patterns, rather than measuring the actual effect of a structure to the environment. Nature-friendly or ecological projects and cities now represent the concepts of brand value. The common point of these projects is to define ecological life independent of the surrounding urban geography reducing it to the

private space. Sonay Aykan (2014) draws attention to the necessity of redefining urban politics in view of the principle of sustainability. The crucial actions to be taken in this regard are to define sustainability at the local level, to build sustainability indicators, to make sustainability reporting and long-term participatory policies in urban area.

### **Approaches to Sustainability: The Case of International High-rise Award 2014/2015**

Ecological skyscrapers are concerned with sustainability issues that affect the system and scale of the high-rise building and design areas that examine the environmental impact of the building. Architectural images that integrate ecological data into vertical dense architectural design through various interiors and landscapes are rapidly increasing across the world. Considering the rise of high-rise housing, the ecological characteristics become as important as the design of housing structures besides functionality and design. The ecological skyscraper is used as an effective architectural image encoded with the signs of *natural environment* and *green building* for residents in the urban fabric. Sustainability approaches explaining the integration of ecological factors into architectural design are examined through five finalist projects of International High-rise Award 2014/2015.

The first phase of the analysis deals with the content analysis of the project in terms of criteria such as scale, location, form, function and plan relationships. The second phase of the analysis engage with ecological and sustainability criteria asking the integration between the building design and the natural environment, the use of natural resources and energy, the design methods used for the ecological architecture. The third phase of the analysis examines the adaptation to the climate and the geography considering the relationship between the high-rise building and its urban context.

#### ***Bosco Verticale by Boeri Studio, Milan, Italy (The Prize Winner)***

Designed by Boeri Studio, in the centre of Milan, the high-rise project consists of two residential towers, which are respectively 122m and 78m height. Bosco Verticale brings landscaping into the building and allows a re-greening of the city in a way that become explicitly a role model for high-rise development in a dense urban area. Two residential towers are developed as part of the revitalization project of Milan, which aims to create a compacter city while adhering to environmental principles. Besides these two residential towers, 75,282 sqm site area also contains an office high-rise and a perimeter row of buildings surrounding them. The green residential towers have a rectangular ground plan and the floors are arranged around a central core with elevators and stairs, where they create terraces and balconies planted with shrubs and trees (Figure 2).



**Project:** Boeri Studio  
**Location:** Milan, Italy  
**Year of Built:** 2009-2014  
**Function:** Residential  
**Height:** Tower D-78 m,  
Tower E-122 m  
**Site area:** 75,282 sqm  
**Net floor area:** 24,060 sqm

Figure 2. The image showing the content analysis Bosco Verticale towers, Milan (Schmal, 2014).

Considering *ecological and sustainability criteria*, large number of the plants on the façades leads to the absorption of dust and carbon dioxide, they produce oxygen and improve the microclimate of the towers. In addition to that, the landscaped façades provide shade for balconies and flats, thereby saving energy. Each of the 400 differently sized flats has access to at least one terrace or balcony. The residential towers are covered in around 900 trees, combined with shrubs, bushes and flowering groundcover, reflecting a diverse flora for each high-rise building. There are obvious benefits for the microclimate in having such extensive greenery on a building: oxygen production is increased thanks to the conversion of carbon dioxide by photosynthesis and this also resulted in increased humidity. As a pioneer project of “forested high-rises”, it presents a vivid example of an integration between architecture and nature. The green dress of the towers, due to the density and homogeneity of planting, represents a filter between the inside and outside, creating a striking image of the building.

The relationship between sustainability and urban development is focused on creating a compact urban space and providing green space in the city of Milan. The jury of International High-rise Award not only regards the building design but also evaluate the urban context of Bosco Verticale. Located in Milan’s redevelopment district Porta Nuova, the towers merge with a park and continue in the vertical plane with the vegetation, creating a compact green space in the dense urban area. In relation to population density, each tower corresponds to a 50,000 sqm area of a single-family residential development, and saves on potential commuter traffic. Creating a model for a sustainable residential building and a project for the metropolitan reforestation, it contributes to the regeneration of the environment and urban biodiversity. Due to the vertical continuation of the extensive parklands into the two towers, they form the green core of the newly developed neighbourhood.

### ***The Renaissance Fira Hotel by Ateliers Jean Nouvel, Barcelona, Spain (The Finalist)***

The Renaissance Barcelona Fira Hotel, located in the south part of the Barcelona, involves two parallel high-rise blocks in which the hotel rooms are placed. Between these two blocks, circulation routes and public areas are located in an open space, surrounded by a Mediterranean climate and lined by many of vegetation. According to the jury statement, the building reflects a new typology of a hotel. Depending on the design of intermediate space between two parallel blocks, the building creates a dialogue between inside and outside opening a natural air corridor in the warmth of Barcelona environment contrary to artificial climate systems (Figure 3).



Figure 3. The image showing the content analysis of The Renaissance Fira Hotel, Barcelona (Schmal, 2014).

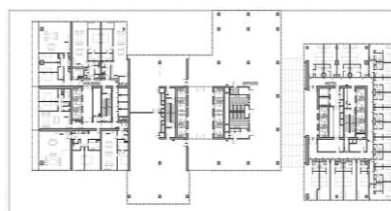
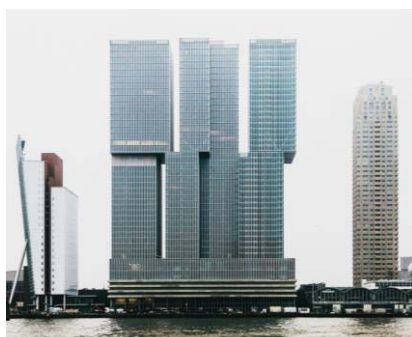


As ecological and sustainability criteria, planting and ventilation of open intermediate space provide natural cooling of the floors and effective shading of the rooms on the exterior façades. Moreover, some of ecological tools such as solar panels, green roof, use of native plants and building materials are integrated into the building design. The building has the certification system of LEED which are used as the sign of sustainability as seen in many projects of high-rises. The exterior façades of the 105 m-height tower are structured by irregular openings that resemble palm leaves instead of an ordinary, regular window layout. The outlines of these openings continue with the adjoining concrete surfaces and create variable shadows in the rooms depending on the direction of incident light. These light effects lead to the differentiation of the rooms from each other thanks to the façade's featured design. While the façade opens onto atrium, the palm-leaf structure provides shade to the hotel rooms and protect them from the direct sunlight. Also, the palm-leaf structure refers to the green in the hotel's interior.

The Renaissance Fira Hotel building is adapted to the Barcelona climate with several architectural solutions that minimize energy consumption. The design of the atrium separating two parallel high-rise blocks opens the building into the exterior space allows the entire of clean air. Walkways and open staircases in the atrium are used as connectors while also being a good viewpoint of the surrounding cityscape. The relationship between the urban area and the high-rise building is created through integration with Barcelona's natural climate and the entire cityscape surrounding area.

#### ***De Rotterdam by OMA, Rotterdam, Netherlands (The Finalist)***

De Rotterdam, designed by Office for Metropolitan Architecture, combines various functions layered and integrated in a single structure. It reflects a vertical city design in the unusual language of the forms used by the architect, Rem Koolhaas. The high-rise complex, which consists of three simple blocks with an elevated podium, rises on the Wilhelmina Pier in the Rotterdam's former harbour. The building's scale corresponds to the height of the Erasmus Bridge, however not to the smaller historic buildings of the former harbour area. The most important design parameter of this project is based on the perception of the building's size and mass from pedestrians circulating on the Erasmus bridge, measuring the change of view approaching along the curving path. However, the high-rise complex seems scale-less resembling a massive mountain, the blocks slipping and sliding past each other with no recognisable sense of proportion considering the smaller historical buildings in the surrounding area (Figure 4).



**Project:** OMA, Rem Koolhaas

**Location:** Rotterdam

**Year of Built:** 2013

**Function:** Mixed-use

**Height:** 151 m

**Site area:** 3,875 sqm

**Net floor area:** 138,390 sqm

Figure 4. The image showing the content analysis of De Rotterdam building, Netherlands (Schmal, 2014).



Considering *ecological and sustainability criteria*, a reduction in energy use (traffic, transport) depending on short distances to various urban activities, use of floor-to-ceiling windows to maximize the entire of daylight, sun reflectors, LED lighting in public areas, use of river water for cooling, flexible space organization capable of conversion are some of ecological design tools integrated into construction process. In addition to that, the rising façades are clad in an aluminium post-and-beam construction that has a filigree feel and seems to change depending on the location of the beholder. It gives the entire complex, whose individual structures are separated from each other by narrow interspaces, a unifying envelope.

The key design principle of De Rotterdam is based on “Vertical City” concept whose diverse functions are seen to be layered on top of each other. The 30 meters- height structure that forms the foot of all three towers houses a parking garage over six floors. An extensive entrance hall on the ground floor provides access to a conference centre, as well as restaurants, bars, gyms. According to the Jury statement (Schmal, 2014), De Rotterdam is opening the scale of the city predicting future density as a model of mixed-use projects for various world cities. The thinking behind this diversity of uses is to contribute to livening up this district in the port area around the clock and encouraging Rotterdam residents to visit the southern part of their city.

#### ***Sliced Porosity Block by Steven Holl Architects, Chengdu, China (The Finalist)***

The sculptural high-rise complex, Sliced Porosity Block designed by Steven Holl Architects in New York encloses a space protected from noise and traffic. Also, it is connected to the surrounding city by several access points, thus making it accessible to non-residents of the five high-rise blocks. The gathering and public space, which has undergone detailed planning, are an inspiring example of high-rise building design and planning in densely populated megacities.

The high-rise complex towers are connected to adjacent buildings through various public entrances. Several landscaped ramps and terraces connect the various public levels of the complex, creating a circulation space between the high-rise blocks and their surroundings. The centre of high-rise office and residential complex has an extensive open space around which five high-rise blocks are located. The design concept of this multi-functional neighbourhood development reflects a more sculptural model than the common residential high-rise complexes in the city (Figure 5).



**Project:** Steven Holl Architect

**Location:** Chengdu, China

**Year of Built:** 2013

**Function:** Mixed-use

**Height:** 123 m

**Site area:** 32,571 sqm

**Net floor area:** 310,000 sqm

Figure 5. The image showing the content analysis of Sliced Porosity Block, China (Schmal, 2014).

In terms of ecological and sustainability criteria, the exterior façade behaves as a heat store and a buffer from the cold, using 468 geothermal walls for heating and cooling of the structure. Using treated rain water for the water circulation of the building and using natural lighting in the underground floors are some of recycling solutions integrated into the building system. At the same time, the high-rise complex adopts energy-efficient domestic technology with use of regional construction materials. Geothermal provision, solar protection glazing and an energy-efficient interior as well as the recycling solutions contribute to energy savings and environmental sustainability of the high-rise complex. In addition to that, most of the building materials are regional, and the certification system of LEED is used as the sign of sustainability as many high-rise projects done.

The irregular form of the structure cuts the amount of shade thrown on the surrounding area. The plasticity of blocks derives from the rate of daylight, producing irregular façade forms with variable angles, slants and protrusions extending over several floors. The high-rise building complex, rising with different size slant of blocks, forms a transition to the smaller residential buildings of surrounding area, creating variable scales. There are small shops on the ground floor that open both to the street and to an indoor shopping arcade and finally to the interior courtyard. According to Jury statement (Schmal, 2014), the designers of the complex have used a massively urban form to create a protected public space in the centre of chaotic metropolis. On the other hand, it provides five access point to the urban fabric for the use of non-residents in the city. The jury accepts that the project represents an unusual type for high-density developments due to its variable scale and functions in the urban area.

#### ***One Central Park by Ateliers Jean Nouvel, Sydney, Australia (The Finalist)***

Designed by Ateliers Jean Nouvel in Sydney, Australia, the One Central Park high-rise building is one of the most striking examples of ecological skyscraper development. It is a mixed-use project, consisting of two towers of different heights that are connected to each other through shared base. The space between the towers, which are also covered in plants, is lighted up naturally via channelling daylight. In addition, the project achieves to create the densification in a city like Sydney. The One Central Park (2012) project rises at the location of the old building of Carlton & United Breweries in the urban renewal area near Sydney central station, aiming to build higher and sustainable housing to reduce land use around Sydney and make life in the city more attractive (Figure 6).



**Project:** Ateliers Jean Nouvel

**Location:** Sydney, Australia

**Year of Built:** 2012

**Function:** Mixed-use

**Height:** 116 m -64,5 m

**Site area:** 25,550 sqm

**Net floor area:** 67,626 sqm

Figure 6. The image showing the content analysis of One Central Park, Sydney (Schmal, 2014).

Considering ecological and sustainability criteria, the design of the project has taken the standards of Australian Green Star certification system as a level to create energy-efficient spaces in environmental and residential development. The structure, consists of two different blocks, 65 m and 116 m in height respectively, separated from each other by an interspace. This intermediate space is largely shaded by the high-rise blocks and can be lightened up with by using daylight technology, heliostat system for shady areas. The 42 heliostats (sunlight reflector) on the roof of the lower of two towers, can reflect the daylight that extends to the 29th floor of the higher tower, which is also equipped with reflectors. Signs such as green facades absorbing carbon dioxide and generating oxygen, natural shade providing for balconies and apartments, irrigation with black water and grey water, power station established to store solar energy, heliostat system set up to illuminate shaded areas have become the main ecological principles of design.

Sustainable urban development aims to realize densification and to provide more greenery and plants in the urban space. According to the Jury statement (Schmal, 2014), the One Central Park creates a very high density of project on a restricted site using various environmental engineering principles. In addition to that, the building's special feature results from its comprehensive use of plants. There are planted balconies, while the green walls of the façades provide natural shading and cooling for the flats behind them. During the hot summer months, this can bring about energy savings of up to %30. The plants process carbon dioxide and produce oxygen, which has a positive impact on the climate of the surrounding area.

## Conclusion

Since high-rise building construction has become widespread with residential and other functional spaces in worldwide, sustainability issue is evaluated as a crucial design principle by many of experts related to urban and architecture disciplines. Considering the change of the skyline of the cities, height is not only matter for high-rise construction and design. As seen in the International High-rise Award 2014/2015, the high-rise projects are analysed in terms of some concepts focusing on sustainability, integration into the urban context, design, technology and on the quality of experience that the building provides users. Innovative ideas and implements in the architectural solutions, design and urban issues, presenting different approaches to sustainability are accepted as the chief criteria for the evaluation process in International High-rise Awards 2014/2015.

International high-rise building awards are not only concerned with the issues such as architectural image, form or scale, but also concerned with the level of integration among high-rise building, ecological data and environmental development. In respect to high-rise building and sustainability, the provision and encouragement of ecological life principles is regarded as one of the main issues. The criteria examined in the context of these five high-rise projects show that the sustainability is evaluated as an issue that should be addressed in urban scale with holistic design principles and not only in building scale. Architectural images that integrate ecological data into vertical dense architectural design through various interiors and landscapes are rapidly increasing across the world. Considering the rise of high-rise housing, the ecological characteristics become as important as the design of high-rise structures besides functionality and design. The ecological skyscraper is used an effective architectural image encoded with the signs of *natural environment* and *green building* for residents in the urban fabric.

In conclusion, sustainability for many segments of society, is transformed into a perception management assembling the terms such as green technology, renewable energy and smart building. Green building practices considering ecological data have entered vertically dense housing design as an important parameter. High-rise buildings generally deal with technological approaches, energy saving and other issues regarding only the ecological aspect of sustainability. However, sustainability is a multidimensional concept that should be dealt with on the physical and economic dimension both on urban scale and building scale. In this context, the difficulties high-rise buildings have caused in the urban area should be evaluated with all aspects of sustainability, and new strategies and approaches should be developed to solve these problems.

## References

- Al-Kodmany, K. (2015). *Eco-towers: Sustainable cities in the sky*. Boston: WIT Press.
- Aykan, S. (2014). İstanbul'da Kentsel Sürdürülebilirlik. In A. B. Candan & C. Özbay (Eds.), *Yeni İstanbul Çalışmaları, Sınırlar, Mücadeleler, Açılımlar*. İstanbul: Metis Kitap.
- Baba, E., C. (2012). *Tasarım Demokrasisi ve İstanbul: Küreselleşme Sürecinde Yüksek Yapılaşma*. İstanbul: Sosyal Yayınlar.
- Firley, E., & Gimbal, J. (2011). *The urban towers handbook*. Chichester: John Wiley & Sons.
- Ghertner, A. D. (2011). *Rule by aesthetics: world-class city making in Delhi*. New York: Wiley-Blackwell.
- Groat, L. N., & Wang, D. (2013). *Architectural research methods*: John Wiley & Sons.
- Hamzah, T. R., & Yeang, K. (1994). *Bioclimatic Skyscrapers*. London: Elipsis.
- Kim, J.-J., & Rigdon, B. (1998). *Sustainable architecture module: introduction to sustainable design*: National Pollution Prevention Center for Higher Education.
- McLennan, J. F. (2004). *The philosophy of sustainable design: The future of architecture*: Ecotone publishing.
- Schmal, P. C. (2014). *Best High-Rises 2014/15: The International High-Rise Award* London: Prestel Publications.
- Short, M. (2007). Assessing the impact of proposals for tall buildings on the built heritage: England's regional cities in the 21st century. *Progress in Planning*, 68(3), 97-199.
- Wood, A. (Ed.) (2011). *Best tall buildings 2008: CTBUH international award winning projects*. New York: Routledge.
- Zuo, J., & Zhao, Z.-Y. (2014). Green building research—current status and future agenda: A review. *Renewable and Sustainable Energy Reviews*, 30, 271-281.



# A Design Chart to Determine the Dimensions of a Solar Envelope as a Function of the Latitude and the Geometry of the Site

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**Abstract:** The main objective of this paper is to introduce a simple quick tool for architects and urban designers, represented by a design chart that determines the dimensions of a solar envelope as a function of the latitude and the geometry of the site.

Solar envelopes are mainly designed to assure maximum access of direct solar radiation, which is needed for maximizing passive solar heating especially in the upper latitudes where cold climates exist. Such constructed envelopes or forms could also be used in lower and mid latitudes while designing certain elements such as: skylights, sunspaces, monitors, etc., that could be used in cooling of such hot or temperate climates.

This design chart involves the integration of both horizontal solar angles (AZI) and vertical solar angles (ALT) to design and construct the required solar envelope with its different dimensions, ensuring the optimization of the direct solar radiation access within the selected hours (cut-off times), for any city all over the world, if knowing its own latitude (LAT).

**Keywords:** Design Charts, Solar Envelopes, Climatic Envelopes, Solar Geometry

## Introduction

A solar envelope signifies the maximum volume that could be built without providing shading to itself or adjacent parts along a given period of time (Baer, 1982). So, constructing solar envelopes is important to ensure maximum access of solar radiation that could be used directly or indirectly. That maximum solar access could be used directly for passive solar heating needed in upper latitudes, where cold climates exist, or it could be used indirectly for providing cooling needed for lower and mid-latitudes, where hot or temperate climates exist.

When the solar envelopes are constructed, pyramidal or crystal-like forms are generated (Watson, 2003). But, since these forms represent the maximum buildable volumes, they could be articulated by the designers to result in varying forms and elements that might include pitched roofs, terraces, etc., resulting from the intersection between the common rectangular geometry of construction and the unique sloping planes of the solar envelopes (see Figure 1). Solar envelope could be constructed at both scales; architectural scale (scale of a building), as well as urban scale (scale of a block or a neighbourhood). The urban scale would result in higher volumes that would enable the existence of higher buildings at the centre of the settlement.

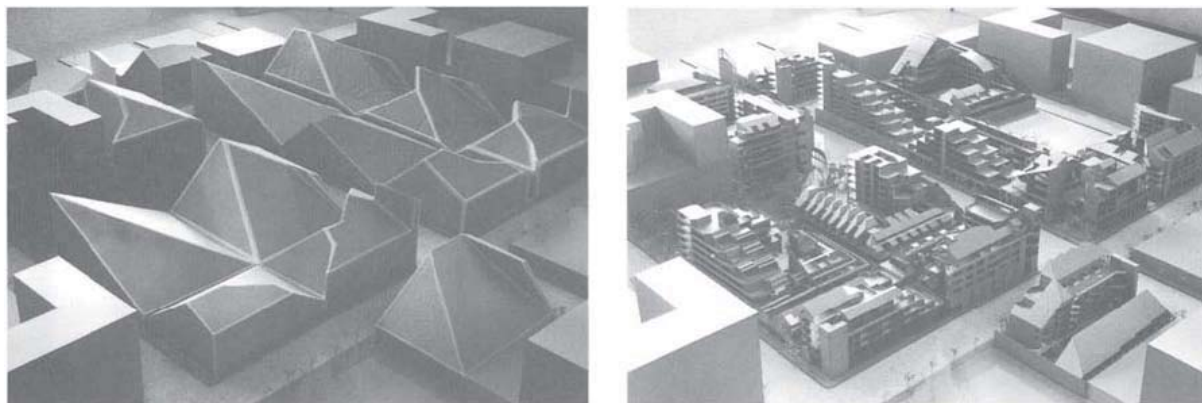


Figure 1: Southpark Housing Project, Los Angeles, 1982.  
Solar envelopes on the left versus design studies on the right.



Constructing a solar envelope is a geometrical task that involves the use of both horizontal and vertical solar angles when the sun is in its lowest (December) and highest (June) positions in the sky, to find its different dimensions. Its shape and size are functions of a lot of variables such as: the latitude that signifies the location of the site, its shape, size and orientation and the cut-off times that signifies the time and duration of desired solar access.

The solar envelope consists of a ridge line and utmost four diagonals; north western, north eastern, south western and south eastern. And because of the fact that the patterns of the shadow are casted in the opposite direction of the sun path, the morning readings define the western diagonals, while the afternoon readings define the eastern diagonals, and December readings define the northern diagonals, while June readings define the southern diagonals see Figure 2).

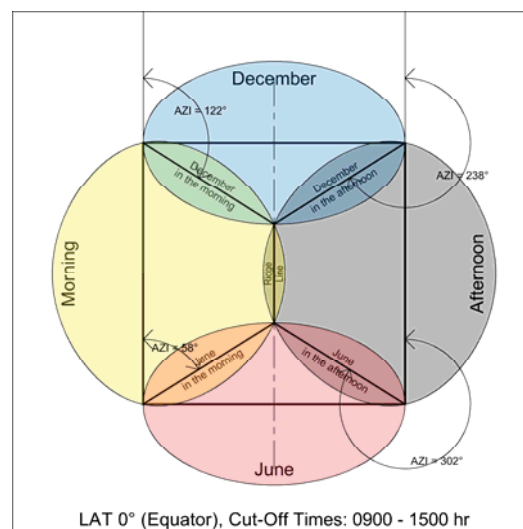


Figure 2: Components of a solar envelope are a ridge line and utmost four diagonals.

### Nomenclature

AZI	azimuth angle	°
AZla	azimuth angle at December in the afternoon	°
AZlb	azimuth angle at June in the afternoon	°
ALT	altitude angle	°
ALTa	altitude angle at December	°
ALTb	altitude angle at June	°
LAT	latitude	°
X	horizontal dimension of the site	m
ya	vertical dimension of a solar envelope between the northern edge and the point of intersection (a) between December diagonals	m
yb	vertical dimension of a solar envelope between the southern edge and the point of intersection (b) between June diagonals	m
yr	vertical dimension of a solar envelope between the northern edge and the horizontal ridge line	m
h	height of a solar envelope	m

### Background and Previous Studies

Previous studies, such as (Brown & DeKay, 2001) proposed methods of sizing for solar envelopes in the form of tables showing the different dimensions in plan, involving several variables; cut-off times, latitude, plan angle, horizontal and vertical dimensions of site and ridge orientation.

In this paper, the author tries to represent a quick tool for finding all dimensions needed to construct a solar envelope, not only the horizontal dimensions in plan, but also its height in elevation. Unlike other studies, the proposed method of sizing for solar envelopes could be characterized by being simple and more generic.

The simplicity lies in describing the geometry of the site in terms of a single variable which is the horizontal dimension of the given site (length), while being more generic because it is in the form of a design chart, which in turn makes it applicable for any location (city) within the low or middle or high latitudes.

## Main Objectives and Hypothesis

The main objective of this paper is to introduce a simple quick tool for architects and urban designers, represented by a design chart to determine the different dimensions of a solar envelope as a function of the latitude and the geometry of the site.

The main hypothesis for this paper is the possibility of determining the different dimensions of a solar envelope as a function of the horizontal dimension of the site only, when using curves that signifies the horizontal and vertical solar angles along the different latitudes.

## Methodology

In this paper, the author tries to use a methodology that he had used in designing previous charts, concerned mainly with solar geometry (Saifelnasr, 2015). To carry out the aimed design chart, a number of measuring techniques were used associated with some simplifications and assumptions as follows.

### Used Measuring Techniques

Constructing a solar envelope is a geometrical task that involves the use of both horizontal solar angles (AZI) as well as vertical solar angles (ALT). And the different curves within the design chart signify these solar angles for the selected hours (cut-off times). Thus, the different dimensions needed to construct a solar envelope, could be determined as a function of the horizontal dimension of the site ( $X$ ), i.e., as ratios with ( $X$ ); ( $y_a/X$ ), ( $y_b/X$ ) and ( $h/X$ ) at the selected cut-off times (see Figure 3).

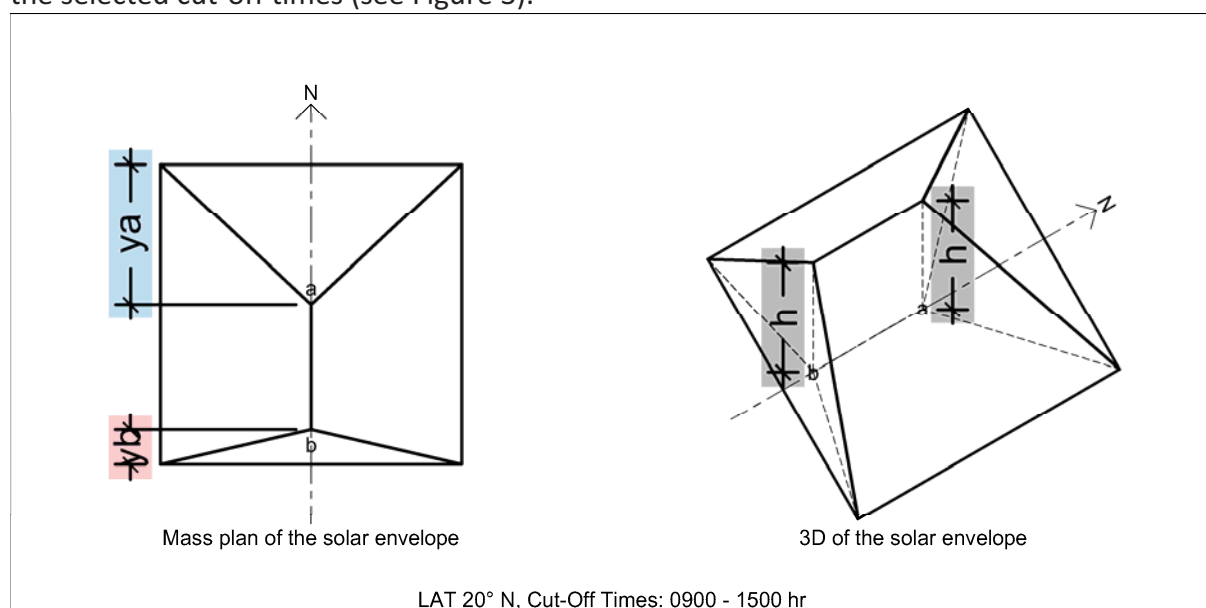


Figure 3: The different dimensions of a solar envelope that could be obtained from the design chart as ratios with ( $X$ ); ( $y_a/X$ ), ( $y_b/X$ ) and ( $h/X$ ).

## Simplifications and Assumptions

Some experimentation parameters, simplifications and assumptions are considered in the design chart concerning its *applicability*, *Selected cut-off times* and *specifications of the used base cases*.

**Applicability of the design chart:** it is applicable for sites with rectangular shapes, oriented towards the main orientations; north, south, east and west. And it could be used in lower middle and upper latitudes ranging from LAT 0° (equator) to LAT 60° N and S.

**Selected cut-off times:** to show the diversity in the amount of the desired day solar access as well as the suitability for the different latitudes, three different intervals of cut-times are used; 0900-1500 hr., 1000-1400 hr. and 1100-1300 hr.

**Specifications of the used base cases:** the shape of the site is a square, oriented towards the main orientations; north, south, east and west, and found in the northern hemisphere.

## Results

Figure 4, Figure 5, Figure 6, Figure 7, Figure 8, Figure 9, and Figure 10, show different solar envelopes that are constructed for a base case site, whose shape is a square (X:Y = 1:1), at different latitudes; LAT 10°, LAT 20°, LAT 30°, LAT 40°, LAT 50° and LAT 60°, and proposed cut-off times; 0900-1500 hr, 1000-1400 hr and 1100-1300 hr.

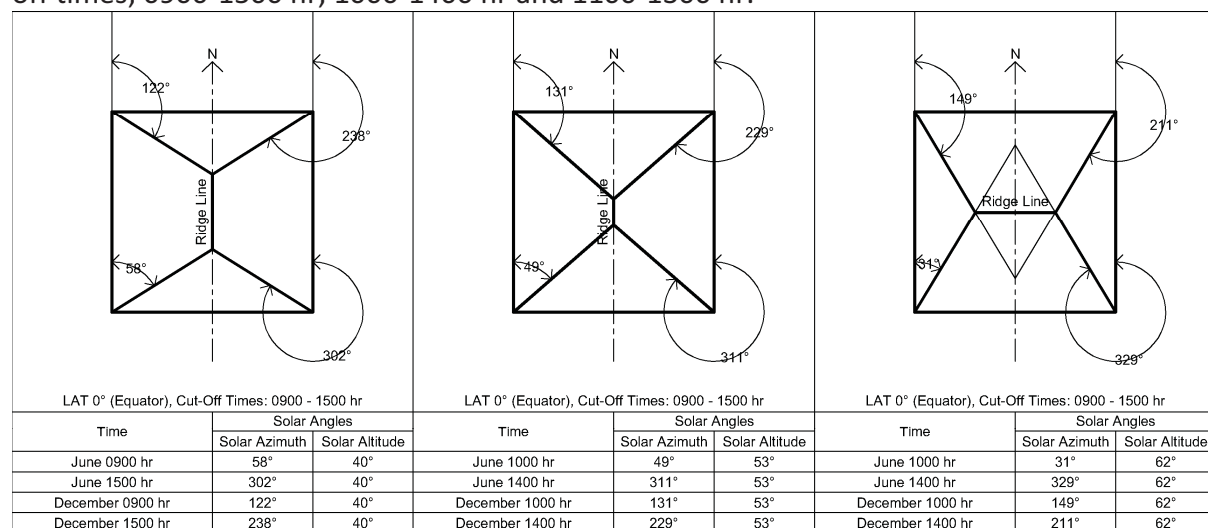


Figure 4: Different solar envelopes constructed for latitude 0° (equator) at selected cut-off times.

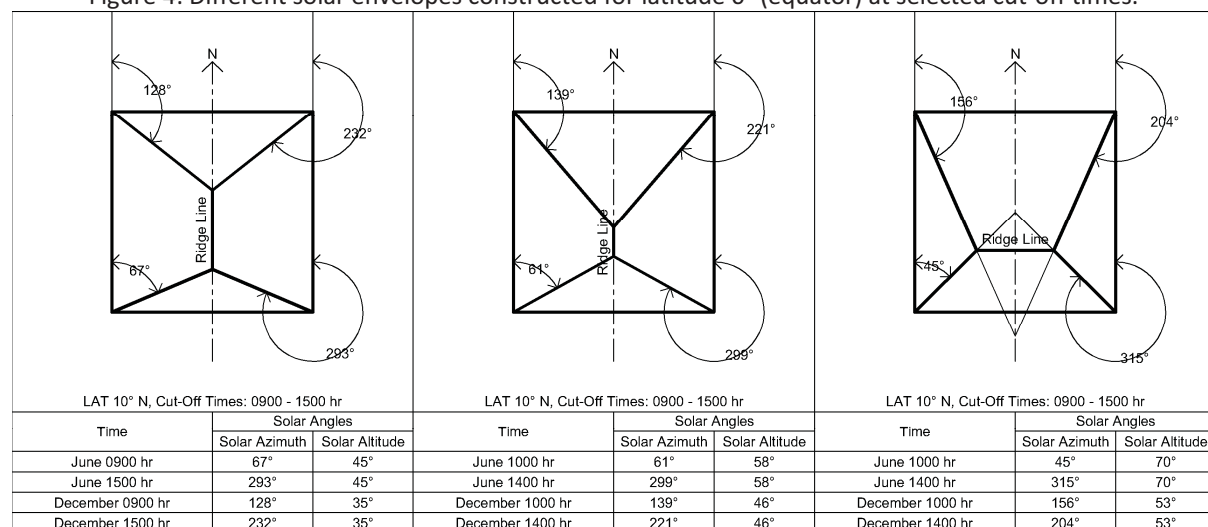


Figure 5: Different solar envelopes constructed for latitude 10° N at selected cut-off times.

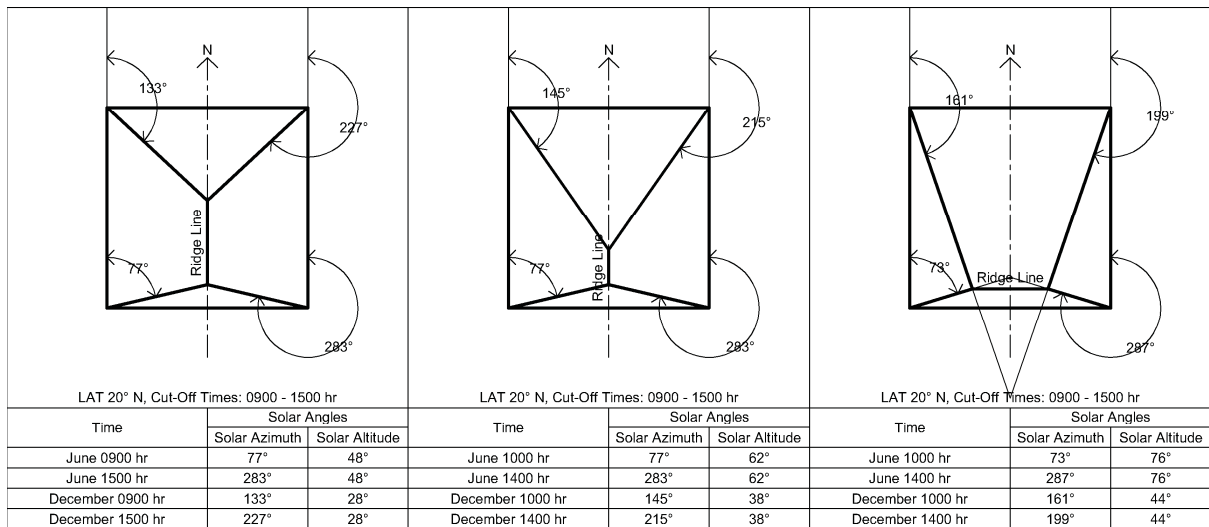


Figure 6: Different solar envelopes constructed for latitude 20° N at selected cut-off times.

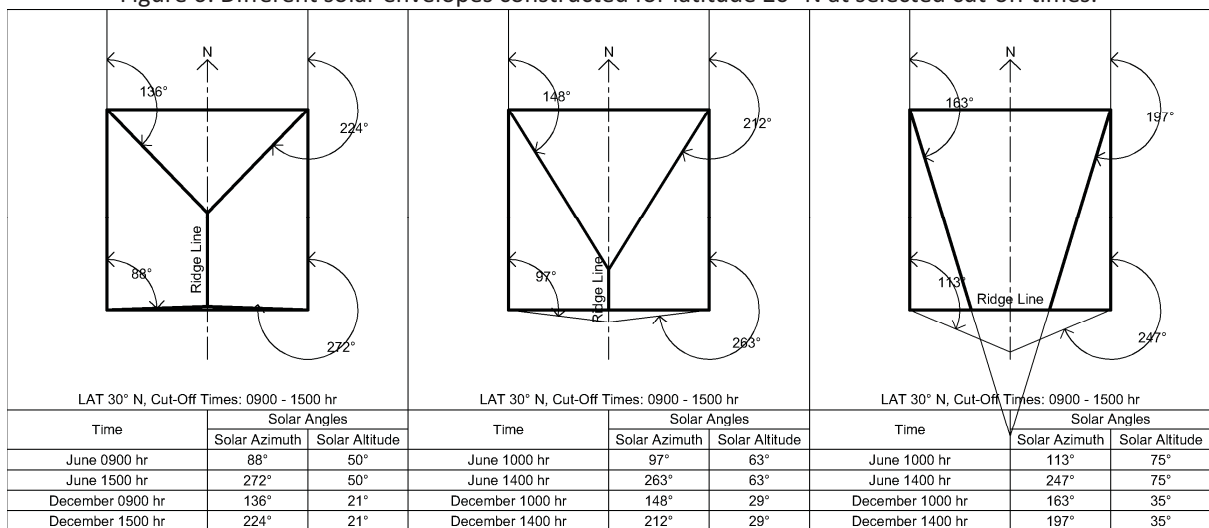


Figure 7: Different solar envelopes constructed for latitude 30° N at selected cut-off times.

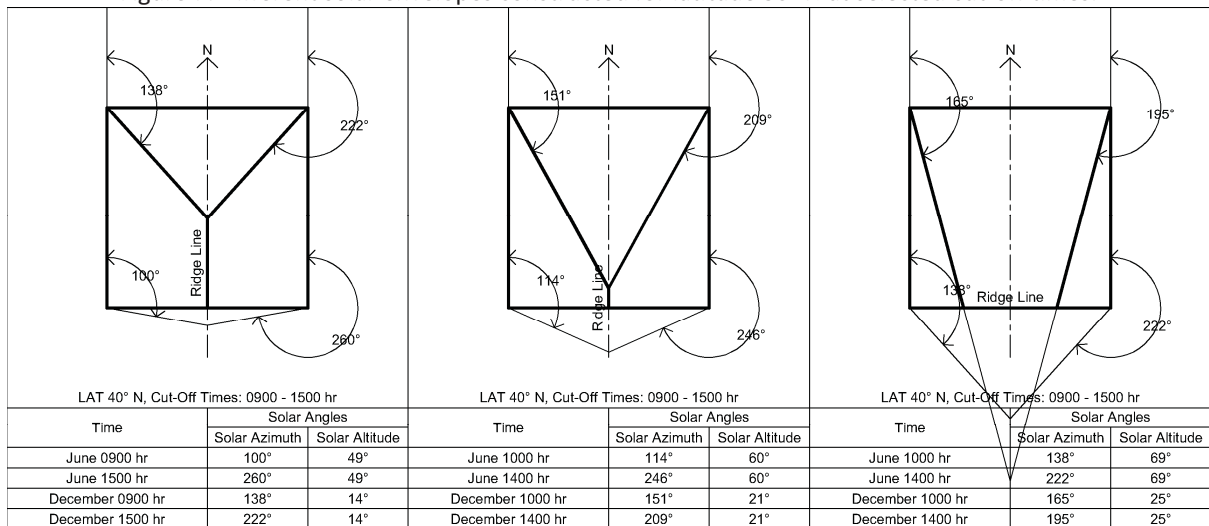


Figure 8: Different solar envelopes constructed for latitude 40° N at selected cut-off times.

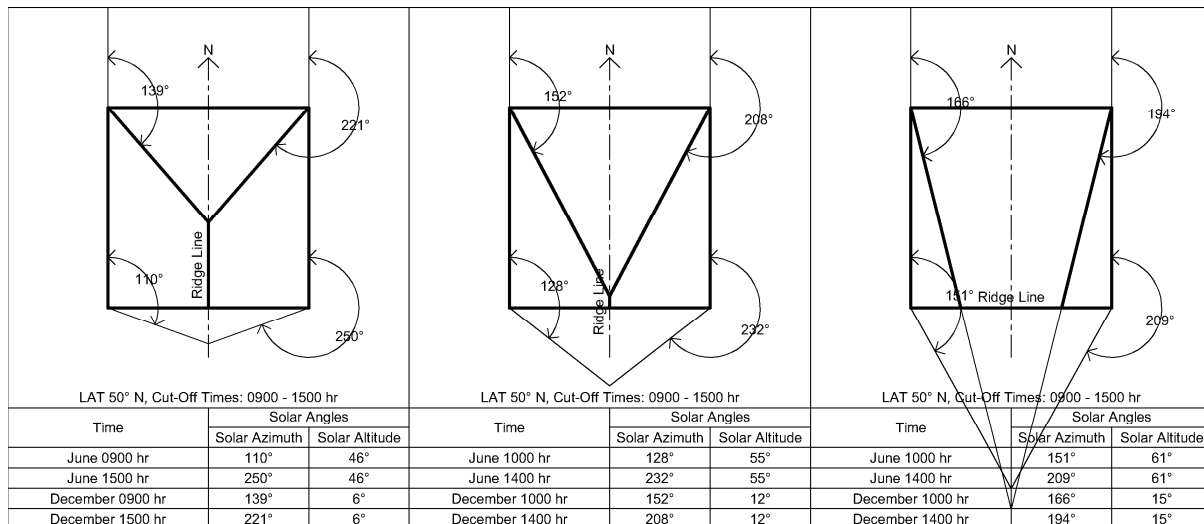


Figure 9: Different solar envelopes constructed for latitude 50° N at selected cut-off times.

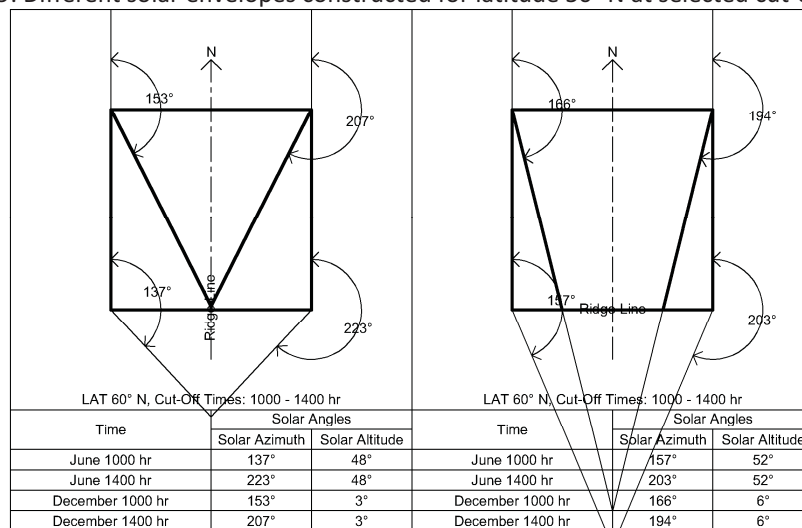


Figure 10: Different solar envelopes constructed for latitude 60° N at selected cut-off times.

### Description of the Design Chart

The design chart shown in Figure 11 is used to obtain the different dimensions of a solar envelope as a function of the latitude (LAT) and the horizontal dimension of the site (X). It consists of nine different curves, including the three ratios representing the dimensions of the solar envelope; (ya/X), (yb/X), and (h/X), within the three proposed cut-off times; 0900-1500 hr, 1000-1400 hr and 1100-1300 hr. And these curves were drawn using the following formulas:

$$\frac{y_a}{X} = 0.5 \times \tan(AZI_a - 90)$$

$$\frac{y_b}{X} = 0.5 \times \tan(90 - AZI_b)$$

$$\frac{h}{X} = 0.5 \times \tan(ALT_a) / \cos(AZI_a - 90)$$



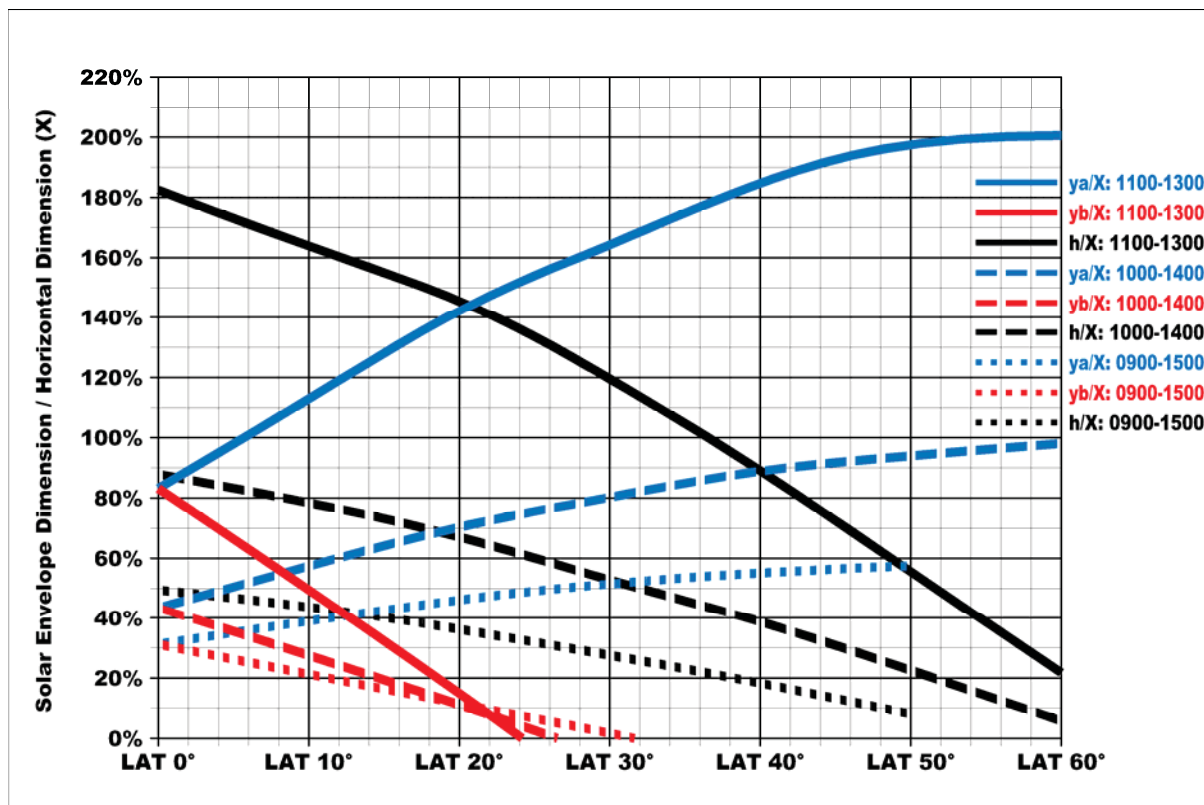


Figure 11: The design chart to determine the different dimensions of a solar envelope.

### Verification of the Formulas

Table 1 shows the mathematical verification of the different formulas used in finding the different dimensions of a solar envelope, by comparing the calculated values using those formulas with the measured values from the different proposed cases. These values are found to be equal and completely match, which in turn verifies that the used formulas are valid.

Table 1: The mathematical verification of the used formulas used in finding the different dimensions of a solar envelope.

#	LAT	Cut-Off Times	Solar Angles			Measurements from Base Case			Calculations Using the Formulas			
			AZ1a	AZ1b	ALTa	ya/X	yb/X	h/X	$0.5 \times \tan (AZ1a-90)$	$0.5 \times \tan (90 - AZ1b)$	$0.5 \times \tan (ALTa) / \cos (AZ1a-90)$	
1	LAT 0°	0900-1500 hr	122 °	58 °	40 °	31%	31%	49%	31%	31%	31%	49%
2		1000-1400 hr	131 °	49 °	53 °	43%	43%	88%	43%	43%	43%	88%
3		1100-1300 hr	149 °	31 °	62 °	83%	83%	183%	83%	83%	83%	183%
4	LAT 10°	0900-1500 hr	128 °	67 °	35 °	39%	21%	44%	39%	21%	21%	44%
5		1000-1400 hr	139 °	61 °	46 °	58%	28%	79%	58%	28%	28%	79%
6		1100-1300 hr	156 °	45 °	53 °	112%	50%	163%	112%	50%	50%	163%
7	LAT 20°	0900-1500 hr	133 °	77 °	28 °	47%	12%	36%	47%	12%	12%	36%
8		1000-1400 hr	145 °	77 °	38 °	71%	12%	68%	71%	12%	12%	68%
9		1100-1300 hr	161 °	73 °	44 °	145%	15%	148%	145%	15%	15%	148%
10	LAT 30°	0900-1500 hr	136 °	88 °	21 °	52%	2%	28%	52%	2%	2%	28%
11		1000-1400 hr	148 °	97 °	29 °	80%	-6%	52%	80%	-6%	-6%	52%
12		1100-1300 hr	163 °	113 °	35 °	164%	-21%	120%	164%	-21%	-21%	120%
13	LAT 40°	0900-1500 hr	138 °	100 °	14 °	56%	-9%	19%	56%	-9%	-9%	19%
14		1000-1400 hr	151 °	114 °	21 °	90%	-22%	40%	90%	-22%	-22%	40%
15		1100-1300 hr	165 °	138 °	25 °	187%	-56%	90%	187%	-56%	-56%	90%
16	LAT 50°	0900-1500 hr	139 °	110 °	6 °	58%	-18%	8%	58%	-18%	-18%	8%
17		1000-1400 hr	152 °	128 °	12 °	94%	-39%	23%	94%	-39%	-39%	23%
18		1100-1300 hr	166 °	151 °	15 °	201%	-90%	55%	201%	-90%	-90%	55%
19	LAT 60°	1000-1400 hr	153 °	137 °	3 °	98%	-54%	6%	98%	-54%	-54%	6%
20		1100-1300 hr	166 °	157 °	6 °	201%	-118%	22%	201%	-118%	-118%	22%

### Using the Design Chart

To get different dimensions of a solar envelope as a function of the latitude (LAT) and the horizontal dimension of the site (X), the design chart is used as follows.

Specify the latitude of the given site on the horizontal axis of the design chart. Draw a vertical construction line from the marked latitude on the horizontal axis till it intersects the three curves representing the different dimensions; ( $y_a/X$ ), ( $y_b/X$ ) and ( $h/X$ ) for the selected cut-off times; 0900-1500 hr or 1000-1400 hr or 1100-1300 hr. From the three points of intersection, draw three horizontal construction lines till the ratios ( $y_a/X$ ), ( $y_b/X$ ) and ( $h/X$ ) are found on the vertical axis. To get the exact dimensions of a solar envelope, ( $y_a$ ), ( $y_b$ ) and ( $h$ ) should be calculated as follows.

To calculate the vertical dimension ( $y_a$ ) of the required solar envelope, multiply the obtained ratio ( $y_a/X$ ) by the horizontal dimension of the site (X).

$$y_a = \frac{y_a}{X} \times X$$

To calculate the vertical dimension ( $y_b$ ) of the required solar envelope, multiply the obtained ratio ( $y_b/X$ ) by the horizontal dimension of the site (X).

$$y_b = \frac{y_b}{X} \times X$$

To calculate the height ( $h$ ) of the required solar envelope, multiply the obtained ratio ( $h/X$ ) by the horizontal dimension of the site (X).

$$h = \frac{h}{X} \times X$$

*Example:* using the design chart, it is required to find the different dimensions of a solar envelope, that would act as a monitor needed for the enhanced stack ventilation of a building in the city of Cairo, Egypt (LAT = 30° N), given that the dimensions of the opening in the ceiling are: 4.00 m horizontally and 3.00 m vertically, and the required cut-off times are 0900-1500 hr.

*Solution:* from the three curves, the ratios ( $y_a/X$ ), ( $y_b/X$ ), and ( $h/X$ ) for the city of Cairo equal 52%, 2% and 28% respectively (see Figure 12). The exact dimensions of the required solar envelope could be calculated as follows:

$$y_a = \frac{y_a}{X} \times X = 0.52 \times 4.00 = 2.01 \text{ m}$$

$$y_b = \frac{y_b}{X} \times X = 0.02 \times 4.00 = 0.08 \text{ m}$$

$$h = \frac{h}{X} \times X = 0.28 \times 4.00 = 1.12 \text{ m}$$

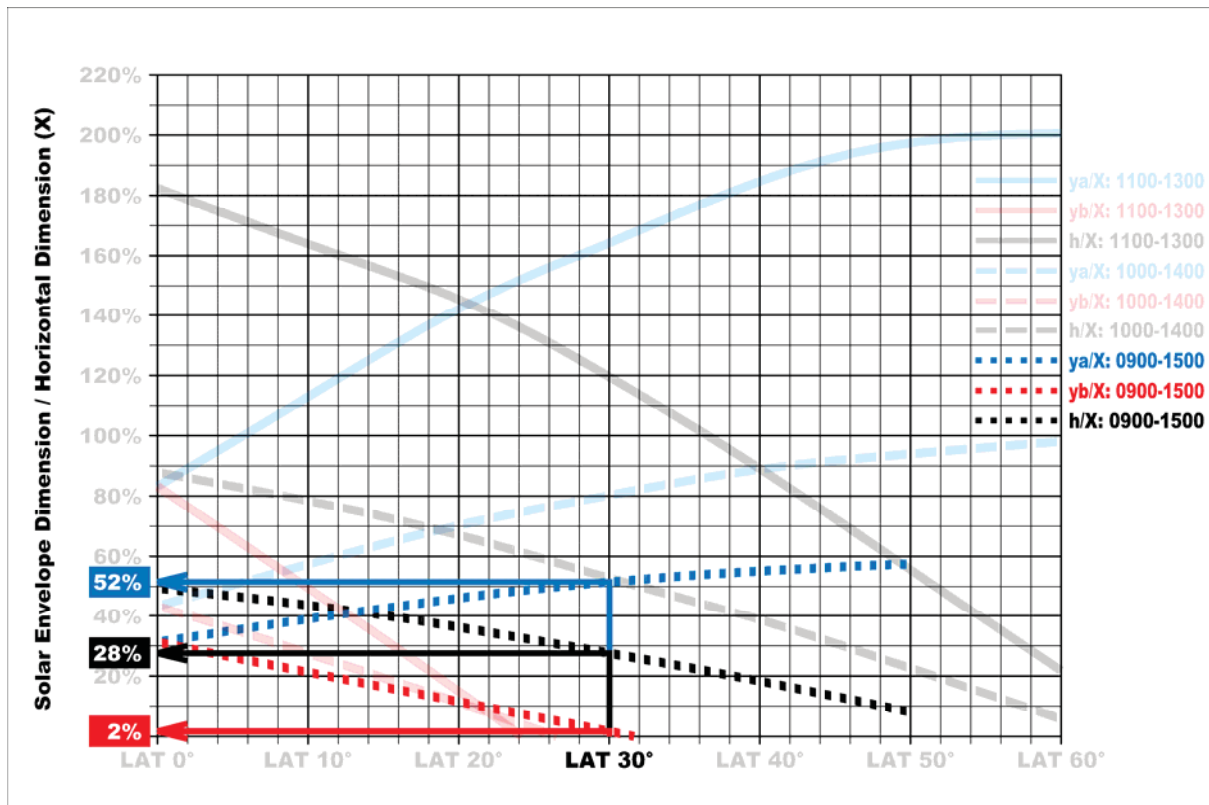


Figure 12: Using the design chart for the city of Cairo, Egypt (LAT = 30° N).

To draw the required solar envelope for the city of Cairo, follow the shown steps in Figure 13.

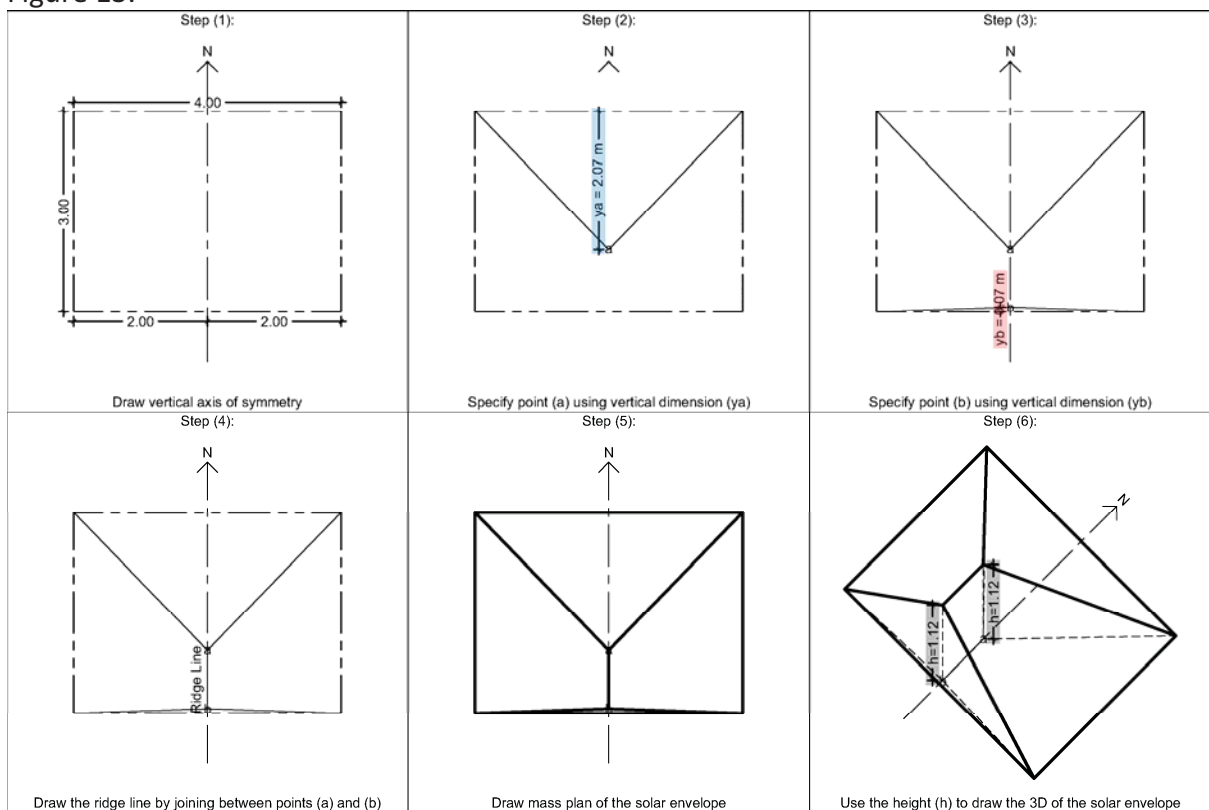


Figure 13: Steps for drawing the required solar envelope for the city of Cairo, Egypt (LAT = 30° N).

### Notes on the Design Chart

**Ridge lines:** either a horizontal or a vertical ridge line would be formed for a constructed solar envelope as a function of the position of points (a) and (b) as follows.

A vertical ridge line would be formed in two cases; either if point (a) is above point (b), or if point (a) only exists within the boundaries of the site (see Figure 14).

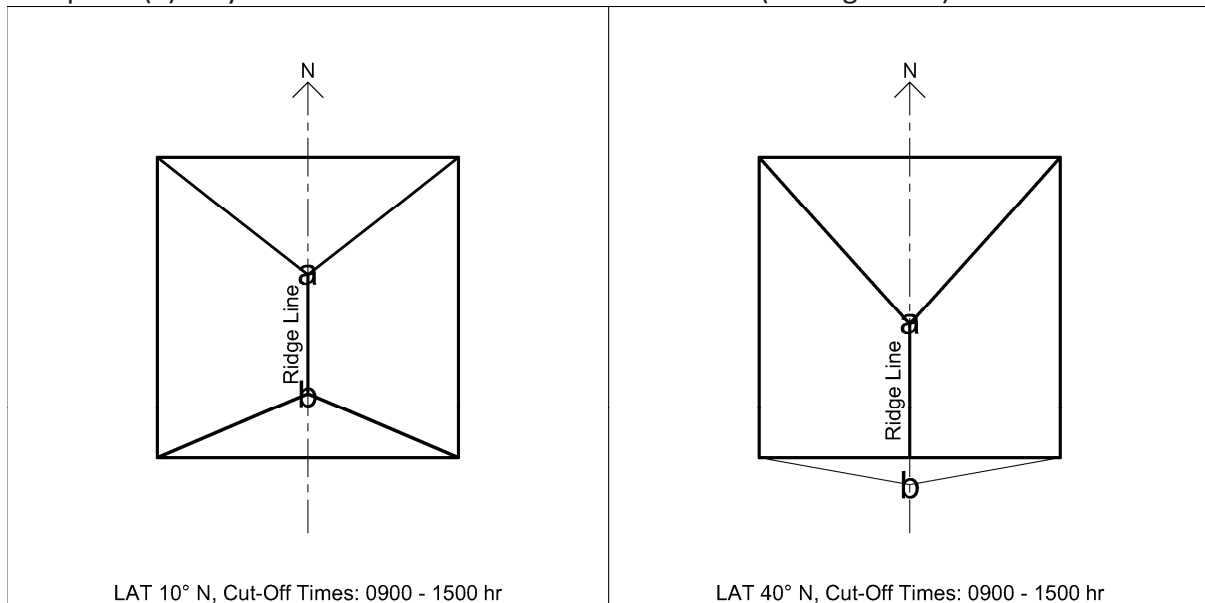


Figure 14: Existence of a vertical ridge line in a solar envelope.

A horizontal ridge line would be formed in two cases; either if point (a) is below point (b), or if point (a) exists outside the boundaries of the site (see Figure 15).

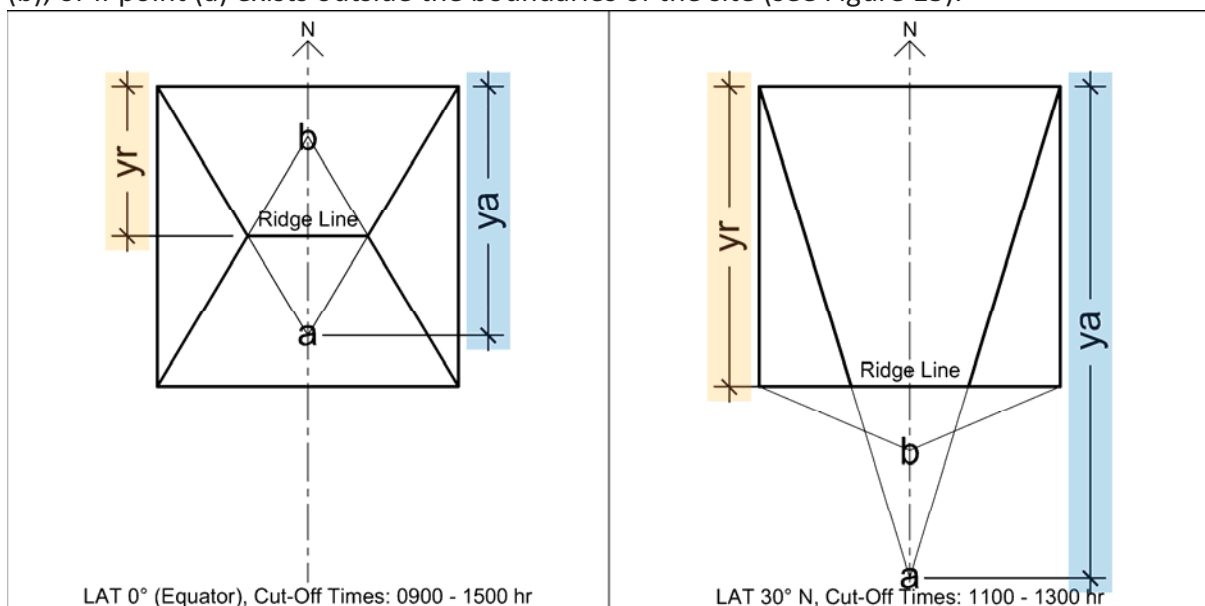


Figure 15: Existence of a horizontal ridge line in a solar envelope.

In the case of the existence of a horizontal ridge line, the obtained ratio ( $h/X$ ) from the chart should be multiplied by another ratio ( $r$ ), that could be calculated as follows.

$$r = \frac{yr}{ya}$$

Where, ( $yr$ ) is the vertical dimension of a solar envelope between the northern edge and the horizontal ridge line, while ( $ya$ ) is the vertical dimension of a solar envelope between the northern edge and the point of intersection (a) between December diagonals (see Figure 15).

*Existence of December and June diagonals:* if point (a) exists below the northern edge, whether inside or outside the boundaries of the site, there are December diagonals. As for point (b), if it exists above the southern edge, there are June diagonals, but if it exists below the southern edge, i.e., outside the boundaries of the site, there are no June diagonals because this indicates that there is no sun in the north (in the northern hemisphere), for the given latitude, at the cut-off times (see Figure 16).

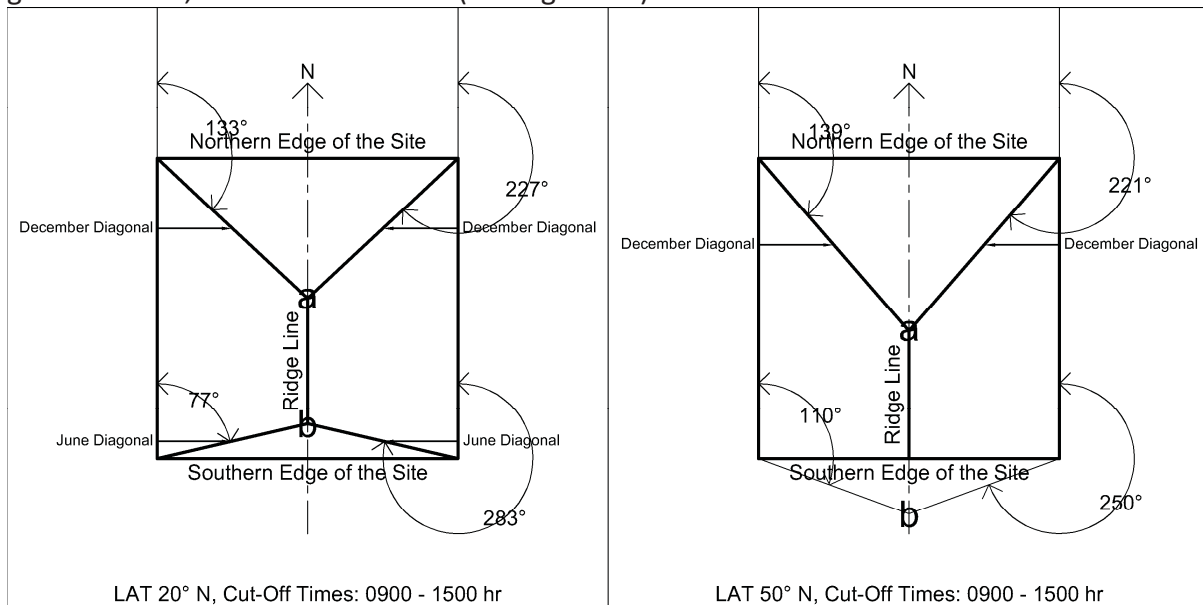


Figure 16: Existence of December and June diagonals.

*Northern versus southern hemispheres:* the design chart is applicable for both northern and southern hemispheres. And since the sun-path diagram for a certain latitude in the southern hemisphere would be exactly the same as the northern hemisphere but flipped along the east-west axis, then similarly, the solar envelope for a certain latitude in the southern hemisphere would be exactly the same as the northern hemisphere but flipped along the east-west axis (see Figure 17).

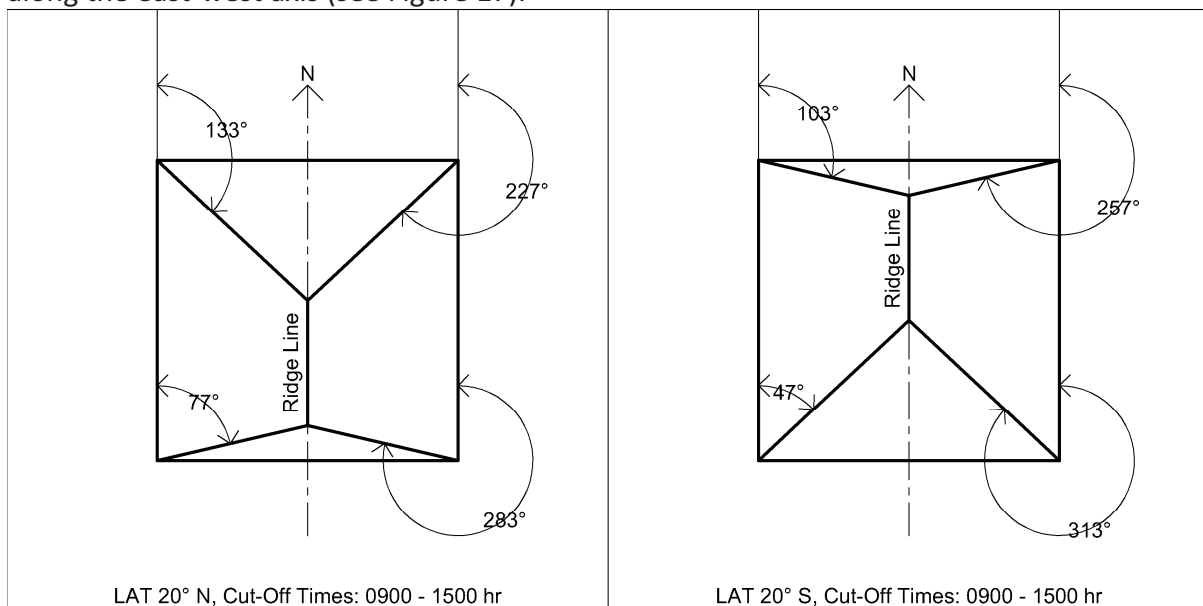


Figure 17: The forms of a solar envelope in the northern and southern hemispheres.



## Discussion and Conclusions

It is possible to determine the different dimensions of a solar envelope as a function of the latitude and the geometry of the site, represented in its horizontal dimension only. Those constructed solar envelopes could be used, not only for ensuring high-quality solar access, but also generating attractive architecture and urban design (Lechner, 2008).

In future researches, this design chart could be upgraded to be suitable for irregular sites or unusual orientations, or it could be upgraded to find specific dimensions or details of a solar envelope that might be suitable for a particular task, e.g., acting as a monitor in stack ventilation, etc. The same methodology could be used for finding the dimensions of other volumes such as self-shading masses, climatic envelopes, etc. Other researches might involve studying the cost effectiveness or efficiency or energy savings that might result from the use of such solar envelopes in the different climates.

## References

- Baer, T., 1982. *Solar Envelope Zoning: Application to the City Planning Process, Los Angeles Case Study*. Washington, D.C.: Solar Energy Research Institute.
- Brown, G. Z. & DeKay, M., 2001. *Sun, Wind & Light: Architectural Design Strategies*. New York: Wiley.
- Chiras, D. D., 2002. *The Solar House: Passive Heating and Cooling*. White River Junction, VT: Chelsea Green Publishing Company.
- Herzog, T., Kaiser, N. & Volz, M., 1996. *Solar Energy in Architecture and Urban Planning*. Munich: Prestel Publishing.
- Knowles, R. L., 1980. *Solar Envelope Concepts: Moderate Density Building Applications: Final Report*. Washington, D.C.: National Technical Information Service.
- Lechner, N., 2008. *Heating, Cooling, Lighting: Sustainable Design Methods for Architects*. Hoboken, N.J.: Wiley.
- Olgyay, A. & Olgyay, V., 1976. *Solar Control and Shading Devices*. Princeton: Princeton Architectural Press.
- Saifelnasr, S. S., 2015. *A Design Chart to Determine the Dimensions of a Horizontal Shading Device over an Equator-Facing Window as a Function of the Latitude and the Shading Height*. Lecce, Italy, Elsevier.
- Steele, J., 1997. *Sustainable Architecture: Principles, Paradigms, and Case Studies*. Eighth ed. New York: McGraw-Hill.
- Watson, D., 2003. *Time-Saver Standards for Urban Design*. New York: McGraw-Hill.

# **The Role of Architects in Promoting Sustainable Principles in the Design of Residential Projects in Amman, Jordan**

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## **Abstract**

Managing energy demand is one of Jordan's major challenges. More than 96% of the country's energy comes from imported oil and gas from surrounding countries. This reliance on foreign energy resources is among the highest in the world, equivalent to 18% of gross national income. Energy use in the residential sector represents 23.1% of the national total (Jaber, Jaber, Mohsen, & Akash, 2003). The need for measures to reduce energy demand is urgent: despite efforts to promote sustainable design solutions, statistics suggest that less than 20% of houses are constructed using energy saving measures such as solar panels or solar heating systems.

The role of architects in addressing wide-scale problems in the built environment, (e.g. energy consumption in the housing sector) is still not fully recognised in the Jordanian context. By studying architect – client communications in the early design stages, this research proposes improvements that demonstrate the additional value that architects can bring to the construction industry, particularly in housing, through improved design quality and building performance, embedding sustainable principles (whether design principles or applications) and saving time and money. As most design decisions are taken in the early design stages and architect-client interactions are most frequent at this time, especially in residential projects, it provides an important opportunity for the architect to promote sustainable design principles and introduce different energy-saving strategies to the client.

This paper is part of ongoing PhD research entitled: 'Complexities of Communication and Practice in Architect-Client Interactions' that aims to investigate early design stage communication between architects and clients in residential projects in Jordan. This paper give insight to the early findings of the empirical work for the PhD research, especially in Architects' understanding of their role in promoting sustainable design principles.

**Keywords:** Architect-client interactions, sustainability, Jordan.

## **Introduction**

Jordan lies in the heart of the Middle-East with an area of 89,318 km<sup>2</sup>. Around 78.4% of it is considered desert or semi desert (Akash, AbuAbdo, Akash, & Mohsen, 2016; Younis, Taki, & Bhattacharyya, 2016). Jordan has a Mediterranean climate, which is hot-dry in summer and cool-wet in winter, though the rainy season is relatively short (Akash et al., 2016). The population has almost doubled over the past decade, reaching 9.53 million in 2015 (including Syrian refugees) (DOS, 2016). The population is highly urbanised, representing about 90.3% of the total population (HUDC, 2016). In 2015 there were 1,977,534 families, with an average family unit size of 4.82. Unlike other neighbouring countries, Jordan is a non- oil producing country. Almost 96% of the country's energy comes from imported oil and gas from surrounding countries (Akash et al., 2016). Due to the instability of the wider region, the supply of oil and gas to Jordan can be intermittently cut. This instability also causes a financial burden on the economy, as energy imports have soared to an annual cost equivalent to 18% of gross national income. This increased cost has to be factored in to investment in important sectors such as health, education and sustainable development. The population of Jordan is expected to exceed 11 million by 2020 (Akash et al., 2016), and the demand on energy is expected to rise further. There is an urgent need for measures to reduce energy demand, and to promote the use of renewable energy sources such as solar energy.

Energy use in the residential sector in Jordan represents 23.1% of total national energy use (Jaber et al., 2003). Around 61% of the energy consumed in the residential sector is used for heating (Younis et al., 2016). At the same time, a large number of residential units in Jordan experience significant energy losses, and it is claimed that new residential units are “not well adapted to the climate” (Johansson et al., 2009). This introduces a significant risk e.g. in a prolonged heat wave it may not be possible to maintain habitable conditions without the use of air-conditioning, this could have a disproportionate impact on the daily life of the citizens especially in the case power cuts. Electricity consumption in the household sector is 41% of the national total (Ministry of Energy and Mineral Resources, 2014).

As part of this ongoing research, and for the purpose of this paper, the PV/ solar heating has been taken as an exemplar sustainable strategy for several reasons; due to its applicability in the Jordanian climate, Because of its efficacy as a stand-alone solution, making it comparable across different projects, and as the pace of its development has made it much more affordable recently, but this has revealed issues in terms of educating sceptical clients.

### **Solar Energy in Jordan**

Jordan benefits from one of the highest levels of solar radiation in the world. Solar energy is considered the most promising type of renewable energy in Jordan. Almost 80% of the land in Jordan is considered to be desert, representing an enormous untapped source of potential renewable solar energy (Akash et al., 2016). The average daily solar radiation is about 5.5kWh/m<sup>2</sup>/d, and the annual sunshine duration is about 3,000 hours (Akash et al., 2016). This makes solar energy the number one choice for renewable energy solutions. Solar energy could be utilised widely in different sectors in Jordan, especially in the housing sector. In residential projects, solar energy could be used in water heating, space heating and cooling and electric power generation.

Solar energy research has received growing attention in recent years at different levels, especially in the academic community. Many universities in Jordan have research programmes examining the implementation of solar energy systems and their application in different sectors of the economy (Akash et al., 2016).

The National Energy Research Centre is a governmental body that coordinates renewable energy research at a national level. It has many projects in the solar thermal division. One of their recent projects is the Self-Sufficient Renewable Energy Air-Conditioning System for Mediterranean Countries project, which aims to establish a pilot cogeneration plant using renewable energy. They also have many research and services available for various energy-consuming sectors (“The National Energy Research Centre,” 2017) .

At a national level, there have been several attempts to promote the application of solar energy in residential units. In 2012 the Renewable Energy Act was introduced. This made it possible for house owners to install solar PV panels to generate electricity for domestic use, the first Arab country to do so. The law also exempted PV devices and equipment from custom duties and sales tax, and introduced subsidies for the cost of connecting with the electricity network (AbuTaer, 2016b). However, by the end of 2015, a total of only 1,542 applications for the installation of solar cells had been received by the

Jordanian Energy and Minerals Regulatory Commission across all sectors (AbuTaer, 2016a). Recently, solar water heating system installation has become mandatory in all new residential buildings, and no Occupation Permit can be granted without it.

In 2014, the Jordanian green buildings code was published, where the use of sustainable principles was promoted.

Despite these efforts to encourage people to employ sustainable principles (such as solar energy and good insulation) in their houses, the lack of uptake on the ground suggests that more efforts need to be made, especially by professionals in practice, including architects. One of the main difficulties is that until recently large housing companies only made up a small part of the residential sector in Jordan. The majority of houses are built by owner-occupiers, so there is little incentive or economy of scale, or opportunity to learn from experience. Recently, housing companies are growing and participating more in the market and this could be a good opportunity to promote the use of solar energy applications more widely in the sector.

## Methodology

This paper is part of an ongoing PhD research project entitled: 'Complexities of Communication and Practice in Architect-Client Interactions', that aims to investigate early design stage communication between architects and clients in residential projects in Jordan. The importance of architect-client interactions, and the implications for the design process, completed buildings and the wider built environment, is well documented in literature<sup>1</sup>. Architect-client interactions continue to occur all through the project life cycle, but they are more frequent and may have a larger impact in the early stages of design, as important decisions are made. The professed aim of architects to serve society as a whole leads to a number of practical, moral, ethical, and conceptual difficulties (Dluhosch, 2006). In each and every design decision that an architect takes, he is expected to consider his or her client, their professional responsibilities, and the interests of society at large.

The value of a home-grown profession in addressing wide-scale problems in the built environment, (e.g. energy consumption in the housing sector) is still not fully recognised in Jordan. By investigating architect-client communications in the early design stages this research explores the existing client understanding of the role of the architect. There is a need to increase understanding of the impact of the architect's role within the community, especially given the growth of the housing sector in recent years. The recent influx of refugees combined with the rise in population means that there will be an unprecedented demand for new housing over the coming decade. The design life of contemporary housing (50-60 years) means this represents an unprecedented but time-limited opportunity to dramatically improve the performance of the entire housing sector for a generation. This research proposes improvements that demonstrate the additional value that architects can bring to society in general and the construction industry, particularly in housing, through

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<sup>1</sup> Some examples are: (E. S. Bertelsen & Stephen, 2005; S. Bertelsen & Emmitt, 2005; W H Collinge & Harty, 2013; William H. Collinge & Harty, 2014; Cuff, 1992; Ivory, 2004; McDonnell & Lloyd, 2014; Norouzi, Shabak, Bin Embi, & Khan, 2014; Norouzi, Shabak, Embi, & Khan, 2015; Oak, 2011; Siva & London, 2011; Thyssen, Emmitt, Bonke, & Kirk-Christoffersen, 2010; Tusa, 2002).

improved design quality and building performance, embedding sustainable principles and saving time and money.

The main contribution of this research is the documentation of empirical examples of architect-client interactions in the design process in Jordan, and evaluation of the strengths and weaknesses of architect-client relationships through Post-Occupancy Evaluation (POE) of selected case studies and interviews with architects, clients, and policymakers. The POE study will predominantly assess user satisfaction with house design and layout, but will also examine energy performance. This will contribute to understanding of this relationship and its implications.

As part of the empirical work for the PhD research, the researcher has conducted sixteen semi-structured interviews with Jordanian architects. Twelve interviews were interviewed face to face in Amman, Jordan, in July/ August 2017, and four interviews were conducted over the internet in September 2017. The interviews were conducted in the architect's offices and were around 50-90 min length. The questions were divided into three categories: the architect-client relationship, the design process (including the promotion of sustainable design principles), and Post-Occupancy Evaluation. Also, case studies from the architect's work were discussed with a focus on early design stages communication. For the purpose of this paper, parts of interviews that examined the architects' role in promoting sustainable principles, including PV installations, were analysed.

## Discussion

During the discussions with the architects, different themes were identified with regard to the architect's role in promoting sustainable design principles. These can be categorised under the following headlines:

### Sustainability as the core of an architect's job:

It was claimed by most of the architects that ensuring sustainability was the core of an architects' job; and its implementation formed part of every day good practice. One architect said:

*"This the core of the architect's job. This is what he should do. The architect should enhance the quality of the client requirements. Introducing sustainable principles is one way to do that. If he does not do that, then he is not an architect." ~ Architect R.A*

Dealing with the subject from this point of view, and redefining the traditional role of the architect from conveying client's requirements, into actively shaping those requirements is very important to introduce new concepts and practices. In many cases, the client knows his or her basic requirements in terms of spaces, function and areas. But in most cases the clients will not ask for special building performance parameters. This could be for several related reasons: for example, the initial relatively high cost of implementation, a lack of understanding of "pay-back time" (the idea that technology will pay itself back in reduced energy bills and eventually lead to long-term savings) and in some cases the lack of knowledge of government incentives for the housing sector. Clients require assistance from the knowledge and experience of the architects to bring their requirements together in the best possible way in terms of design, cost and comfort. This includes the implementation of



sustainable design strategies such as solar panels and solar heating systems. Several architects claimed that even if the client is not aware of these, it is part of their professional practice to pay attention to environmental issues.

#### Educating the client

In everyday architect-client interactions, a dual learning-teaching process can be observed. The interviewed architects claimed that they undertake a lot of client education in every meeting, starting from reading the drawings, to architectural trends and choosing different finishing materials. Some clients have 'false' preconceptions about sustainable principles and the applications of solar energy in houses; for example, assuming that advanced technology is required, doubling the cost of the building, or that it will increase the running cost and maintenance. In some cases, clients have experience of the first generation of solar panels for water heating, which were inefficient, and this failure of technology in the past been an important factor in shaping their views. Clients also do not realise that the cost of PV is now falling rapidly, and how affordable it can be now. Some architects claimed that they spend time informing clients of these developments. They also need to clarify the applications of different technologies, how they be used, and most importantly the actual initial cost and the long-term savings. Architects claimed a key part of their relationship with the clients is to improve their knowledge and 'refine' their decision-making.

Another issue can be seen through the following quotation from one architect:

*"They sometimes do not know what is good insulation. I have a special presentation that I show to the client about the insulation method that we recommend and how it should be applied. We show the client what is the common practice in the market and what is our best practice from our experience. We developed this because we know the method of building and the way the contractors work. So we show the client the different options and he can choose." ~ Architect F.B*

This highlights one of the most important aspects of architect- client interactions – the importance of involving the client in the decision-making process rather than just telling them what is best. Educating the client includes clarifying options that will them take appropriate decisions.

On the other hand, architects highlighted that they also need to update their own knowledge with regard to the applications of solar energy technology in houses, as awareness of new technologies and market prices are required to convince clients to implement these technologies.

#### Architect's decisions and client's decisions

Some architects claimed that the implementation of sustainable principles into design is a shared responsibility between the architect and client. However, some architects claimed that many design solutions can be included without consulting the client as part of

an architect's 'know-how'. The architect – as a service provider – should provide high quality solutions, including consideration of environmental / bioclimatic issues, without the need to consult with the client. Although it should be part of an architect's "know-how", not educating the client risks leaving client behaviour unchanged. This could impact on overall performance if they do not understand how to use technology in their homes.

#### Green/ Sustainable principles or good practice?

Some architects claimed that Green is a 'fancy word' for good practice: *"As an architect, Green principles are part of the right decisions that we need to take in the design stage. The right orientation, the right material, the right insulation and so on"*. This points again to the professional role and the moral responsibility of the architect. As mentioned before, applying the sustainable principles is seen as part of the architect's good practice. This also is important when discussing the architectural education plans and development strategy; where the technology/ sustainable practice need to have more attention in the study plan.

#### Just tell them about the savings!

It is important to highlight this as many architects mentioned it. Some clients do not have a very clear idea about the actual cost of the installation of solar panels. Architects claimed that if the client had a clear idea of how much he or she needed to pay as an initial cost and the amount of savings in the long run, they would choose these strategies from the beginning. One architect claimed it is not always about the environment. This is the case especially in the case of an end-user client. In the case of developers, architects said it was more difficult:

*"In the residential projects, it is very important especially when you convince them with the savings on the running cost. The developers will care much more about the initial cost rather than the running cost."* ~ Architect R.W

Another issue is the insulation cost and benefits. The same idea is revealed again:

*"If you tell them that they will get their money back in a couple of years because you will lose less heat because of the good insulation. You will need less money for heating and cooling so they understand and they want to do that."*  
~ Architect R.L

And:

*"The clients would come and ask for sustainable principles, but they won't come and say that, they want to save some money on the long run. And in the same line this is how I tell them about it. I would say in order to save in the long run you need to have good insulation ..... I think if there is no saving of money in the long run, most clients will not go for those applications. They would also ask for a solar system for water heating, or collecting rain water. But*

*they would state that they want to save and that's why they are asking for those applications. And they ask for solar panels in the roof. But again, they ask for all these applications to save money and not for the environment's sake."* ~ Architect F. B

This shows how architects could convince clients to use different sustainable applications in their houses. There is a need for concrete studies about the benefits of using these applications in Jordan so that architects can refer clients to reliable facts. Architects claimed that clients do not focus on the long-term, including possible rises in energy prices, etc., so it is important to highlight this in the early design stages so that they can consider energy saving alternatives.

#### It is a trend now

On the whole, the interviewed architects claimed that people are more aware of sustainable principles than ten years ago. As these applications are already being used and tested in Jordan, clients have seen them, or know someone who already uses them. This is a very important point. When the applications of a design strategy or technology become more familiar, they will be used more. It is also easier to convince clients to use them. For example, the wide use of improved insulation products compared to ten years ago has made more people aware of the importance of insulation.

### **Conclusion**

This paper has discussed architects' understanding of their role in promoting sustainable principles during the early design stages of private residential projects in Jordan (currently representing 50% of new projects). It was found that architects use economic factors as a persuasive tool to convince clients of the need to apply sustainable design principles in their residential units. It was also found that more effort should be devoted in the early project life cycle to implement sustainable principles at the heart of the design process.

The research has also highlighted the need for further training of architects in persuading clients of the benefits of sustainable technology. The importance of client understanding of passive and active solutions (e.g. the use of PV cells and other solar technologies), and their role in improving energy performance in the medium to long term through their impact on user behaviour, is still not widely understood. Further research is urgently needed, including studies of the energy performance of different housing types broken down by end energy use.

## References

- AbuTaer, M. (2016a). Al Ain record Jordanians' success stories with using solar energy. Retrieved September 19, 2017, from <https://al-ain.com/article/243971>
- AbuTaer, M. (2016b). Jordan as a pioneer arab country in using solar energy. Retrieved from <https://www.addustour.com/articles/18584-الأردن-رائدة-عربيا-في-استغلال-الطاقة-الشمسية>
- Akash, O., AbuAbdo, A., Akash, B., & Mohsen, M. (2016). A review on solar energy reserach in Jordan. In *GCREEDER 2016*. Amman. <https://doi.org/10.1016/j.rser.2010.12.018>
- Bertelsen, E. S., & Stephen. (2005). GETTING TO GRIPS WITH CLIENT COMPLEXITY. *Technical University of Denmark, Denmark*, 61–68.
- Bertelsen, S., & Emmitt, S. (2005). The Client as a Complex System. *13th International Group for Lean Construction Conference: Proceedings*, (JULY 2005), 73–79. Retrieved from <https://lt.ltag.bibl.liu.se/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=edsiec&AN=565895691105823&site=eds-live%5Cnhttp://search.informit.com.au/documentSummary;dn=565895691105823;res=IELENG>
- Collinge, W. H., & Harty, C. (2013). Evolving designs and stakeholder contributions to the briefing process. *Procs 29th Annual ARCOM Conference*, (September), 137–146.
- Collinge, W. H., & Harty, C. F. (2014). Stakeholder interpretations of design: semiotic insights into the briefing process. *Construction Management and Economics*, 6193(February 2015), 1–13. <https://doi.org/10.1080/01446193.2014.894247>
- Cuff, D. (1992). *Architecture: The Story of Practice* (first). MIT. Retrieved from <https://books.google.co.uk/books?id=RA440xSeYQ0C&printsec=frontcover&dq=Architecture:+The+Story+of+Practice&hl=en&sa=X&ved=0ahUKEwilit2479nOAhWrKMAKHdILBFgQ6AEINjAA#v=onepage&q=Architecture%3A+The+Story+of+Practice&f=false>
- Dluhosch, E. (2006). The role of the architect in housing design : Old and new. *ITU Journal of the Faculty of Architecture*, 3(1/2), 5–23.
- DOS. (2016). *Population and housing census 2016*. <https://doi.org/10.1017/CBO9781107415324.004>
- HUDD. (2016). *Urban Indicators (in the Kingdom)*.
- Ivory, C. (2004). Client, User and Architect Interactions in Construction: Implications for Analysing Innovative Outcomes from User-Producer Interactions in Projects. *Technology Analysis & Strategic Management*, 16(4), 495–508. <https://doi.org/10.1080/0953732042000295801>
- Jaber, J., Jaber, J. O., Mohsen, M. S., & Akash, B. (2003). Energy analysis of Jordan commercial sector, 4215(February). [https://doi.org/10.1016/S0301-4215\(02\)00132-5](https://doi.org/10.1016/S0301-4215(02)00132-5)
- Johansson, E., Ouahrani, D., Shaker Al-Asir, H., Awadallah, T., Blomsterberg, Å., Håkansson, H., ... Kvist, H. (2009). *Climate Conscious Architecture and Urban Design in Jordan-towards energy efficient buildings and improved urban microclimate. Report*.
- McDonnell, J., & Lloyd, P. (2014). Beyond specification: A study of architect and client interaction. *Design Studies*, 35(4), 327–352. <https://doi.org/10.1016/j.destud.2014.01.003>
- Ministry of Energy and Mineral Resources. (2014). *Annual Report 2014*.
- Norouzi, N., Shabak, M., Bin Embi, M. R., & Khan, T. H. (2014). Participation Problems and Communication Difficulties in Architectural Design Practice. *Life Science Journal* 2014;11(9), 11(9), 984–990. <https://doi.org/10.1017/CBO9781107415324.004>
- Norouzi, N., Shabak, M., Embi, M. R. Bin, & Khan, T. H. (2015). The Architect, the Client and

- Effective Communication in Architectural Design Practice. *Procedia - Social and Behavioral Sciences*, 172, 635–642. <https://doi.org/10.1016/j.sbspro.2015.01.413>
- Oak, A. (2011). What can talk tell us about design?: Analyzing conversation to understand practice. *Design Studies*, 32(3), 211–234. <https://doi.org/10.1016/j.destud.2010.11.003>
- Siva, J. P. S., & London, K. (2011). Investigating the Role of Client Learning for Successful Architect–Client Relationships on Private Single Dwelling Projects. *Architectural Engineering and Design Management*, 7(3), 177–189. <https://doi.org/10.1080/17452007.2011.594570>
- The National Energy Research Centre. (2017).
- Thyssen, M. H., Emmitt, S., Bonke, S., & Kirk-Christoffersen, A. (2010). Facilitating Client Value Creation in the Conceptual Design Phase of Construction Projects: A Workshop Approach. *Architectural Engineering and Design Management*, 6(1), 18–30. <https://doi.org/10.3763/aedm.2008.0095>
- Tusa, J. (2002). From the viewpoint of a client. *The Journal of Architecture*, 7(4), 349–353. <https://doi.org/10.1080/1360236032000040857>
- Younis, A., Taki, A., & Bhattacharyya, S. (2016). Low-Middle Income Apartments in Urban Amman/Jordan: Energy Challenges and Motivations. In *International Conference on Architecture, Structure and Civil Engineering (ICASCE'16)*. London.



# Enhancing Building Envelope of Existing Residential Buildings and Using PV Panels to Reach nZEB.

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**Abstract:** The aim of this research is to develop a method to be used in solving the decision making and analysis of alternatives for local energy problems related to existing buildings. The method addresses the retrofit strategy with emphasis on the envelope material upgrades. The research suggests using energy simulation and the utilization of the nZEB (net zero-energy buildings) guidelines as well as cost information to develop a decision tool. The outcome of the research combines both retrofitting and renewable energy strategies to convert existing residential buildings to nZEB buildings.

The research utilizes energy simulation to validate the initial assumptions and to test the feasibility of the proposed guideline on a case study building. Another outcome is developing steps of converting existing residential building to an nZEB. Specific retrofit actions are selected, specific PV system is considered and a complete cost analysis as well as a return on investment study is performed. A nZEB building was reached using envelope retrofit and the use of PV panels.

**Keywords:** Retrofit, Zero energy buildings, existing residential buildings, PV panels.

## Introduction

During the last two decades primary energy has grown by 49% and CO<sub>2</sub> emissions by 43%, with an average annual increase of 2% and 1.8% respectively according to the International Energy Agency data for energy consumption trends. It is worth mentioning that 40% of this energy is consumed by the building sector. Predictions for the Middle East - and areas of growing economy- show that this trend will continue to grow at an average annual rate of 3.2% and will exceed the growing rate of developed countries by 2020 (Pérez-Lombard, Ortiz and Pout, 2008). On regional, national and international levels, energy policy is considering energy efficiency in buildings as a future target for the building design. This is why Zero-Energy Building design is recently taking a leading role in all the architecture, the architectural engineering, and the building physics sectors and having a significant importance among researchers on these fields (Deng, Wang and Dai, 2014).

A survey including 1500 apartments in three governorates in Egypt revealed the energy efficiency problem in the existing buildings in the Egyptian context. It showed that all the surveyed buildings suffered from poor thermal performance and indoor air quality. It was found that 80% of the investigated samples used at least one air conditioning unit to overcome the inefficiency. The envelopes of these buildings were described to be of low air tightness, having single glazed openings, walls were non-insulated and no shading treatment was installed (Attia, Evrard and Gratia, 2012). These numbers give a sense of the severity of energy performance of buildings in Egypt.

The study aims at introducing a step-by-step guideline that would convert existing residential buildings to net zero-energy buildings. The guideline will suggest steps for envelope retrofit that will help increase the building's insulation. This in turn increases the building's energy efficiency and consequently energy consumption will decrease. After decreasing the energy consumption, the rest of energy used by the building is meant to be compensated by using photovoltaic panels. The research methodology will start with the literature review that discusses different retrofit actions, nZEB methodologies as well as previous case studies. The research will then explain the proposed guideline, then test it on

a case study building. The study proves that a residential building in Egypt can be converted to nZEB using market available products and at an affordable price.

## Literature review

### Energy situation analysis

Some facts about the energy consumption in Egypt says a lot about the problem. For example, the fact that electricity generation has increased by 500% during the period 1982–2005 from nearly 22 TWH to 108.4 TWH at an average annual growth rate of 6.9%. As a result, oil and gas consumed by the electricity sector has jumped during the same period from around 3.7 MTOE to nearly 21 MTOE (Ibrahim, 2012).

The building sector is account for a 40% of the total final energy consumption, occupying the third place after industry and transport sectors. Moreover, expected growth of energy use in the built environment in the next 20 years is 34%, at an average rate of 1.5%. The residential sector will contribute with 67% of the energy consumption in 2030 and 33% for the non-domestic sector (Pérez-Lombard, Ortiz and Pout, 2008). The next section analyses the reasons behind this high level of energy consumption by residential buildings.

### Energy performance of buildings in Egypt

In its latest published report for the year 2013/2014, the ministry of electricity and renewable energy stated that 51.3% of the overall electricity consumed goes to the residential buildings as seen in figure 1 (Eehc, 2015). Another study provides energy breakdown data through surveying the electricity usage in an urban community in Cairo. The study revealed that 74% of the electricity used is consumed towards reaching thermal comfort, where 65% goes to cooling purposes while 9% goes to heating ones. Figure 2 shows the exact breakdown of the energy usage according to Attia's study (Attia, 2013). This shows the importance of solving the thermal comfort aspects and proves that if the building insulation efficiency was enhanced, the energy saving will be significant.

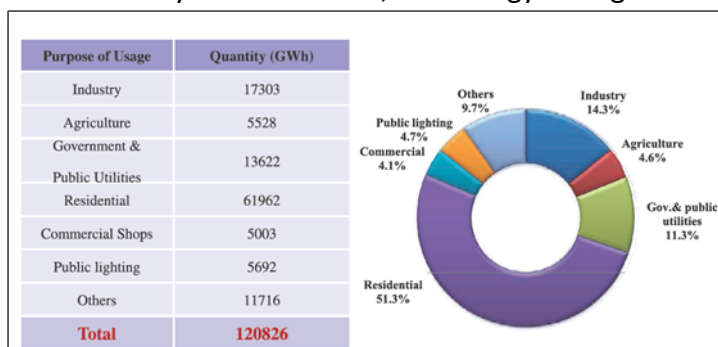


Figure 1. Amount and percentages of energy sold according to purpose of usage.

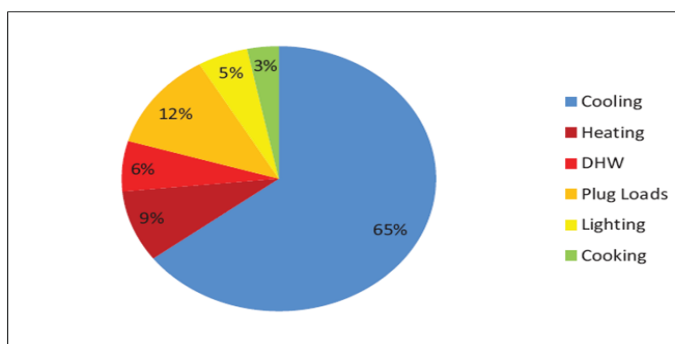


Figure 2. Energy consumption per household in an urban community in Cairo.

### Thermal inefficiency

Buildings in Egypt are characterized by low levels of insulation from what leads to a very poor thermal performance and low indoor air quality. A survey conducted by (Attia, Evrard and Gratia, 2012) revealed that the building envelopes of the surveyed buildings were not airtight, all the openings were single glazed, walls were not insulated and no shading treatment was provided. To compensate for this technical problem, 80% of the apartments installed at least one air-conditioner unit, and this leads to the peak electric loads that causes failure and complete shutdown of the grid, as experienced recently in Egypt. It is worth saying that the final survey findings showed that the use of air-conditioners raised the annual electricity bill by 44% to 57% in Cairo.

Thermal inefficiency has two main aspects:

- Envelope: The envelope performance controls the amount of heat transmitted to and from the building. So, its status reflects directly on the building's energy consumption. The envelope is composed of walls, windows, roofs and shading system –if applicable.
- Efficient Systems: The second main aspect is the appliances in general and particularly the HVAC system. Most importantly comes the HVAC system because if the cooling system is efficient it will consume the least amount of energy to perform. While if the system is worn out it may consume a large amount of energy and not fulfill the occupant demand. The rest of the electric appliances also play an important role in energy saving.

### Solar energy potential

On the other hand, literature say that Egypt's potential of solar energy is 40,000 tetra watt hour per year, while the total installed capacity is around 21,435 MW. Although Egypt has a very high potential compared to other countries in the world, the installation capacity does not reflect the same value, as shown in figure 3, both the PV panels and CSP represent 1% of the total installed capacity in Egypt ('NREA', 2015, *Potential of solar thermal energy*, 2015). This potential makes solutions that include renewable energy a feasible solution. An example of these solutions is nZEB, which will be thoroughly described in the following section.

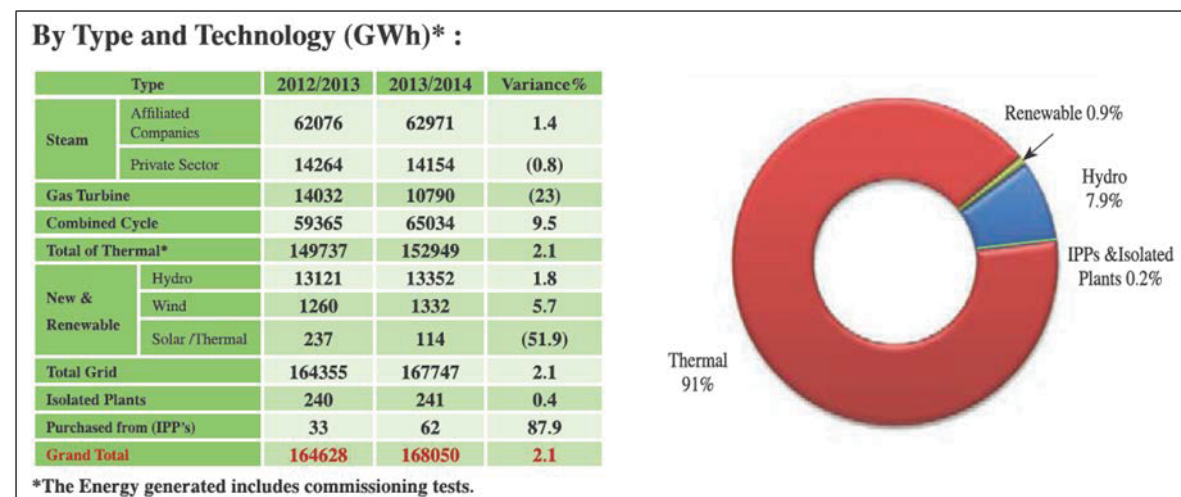


Figure 3. Generated and purchased energy in Egypt.

### **Net-zero Energy buildings (nZEB)**

A clear definition of the nZEBs is: "A zero energy building refers to a building with a net energy consumption of zero over a typical year. It implies that the energy demand for heat and electrical power is reduced, and this reduced demand is met on an annual basis from renewable energy supply" (Wang, Gwilliam and Jones, 2009). Figure 4 shows the three main phases of reaching net zero energy buildings.

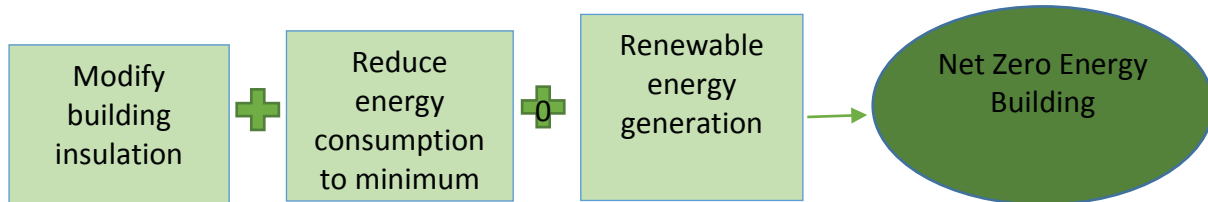


Figure 4. Aspects of reaching net zero-energy building

There is no specific guidelines or design strategies to act as a clear methodology for nZEB design process, yet some research have defined three basic steps to be followed (Wang, Gwilliam and Jones, 2009; Szalay and Zöld, 2014; Sun, Huang and Huang, 2015)(Sartori, Napolitano and Voss, 2012)(Deng, Wang and Dai, 2014; Garde *et al.*, 2014).

#### **1. Data Collection and Analysis:**

The first and primary step on the way of zero-energy building approach is the collection and analysis of local climate data in order to assess the climate potential and make important decisions. For example, building's energy system design and renewable energy system selection will be determined according to the results of the analysis. Wind, Solar radiation and ambient temperature are the main aspects that should be studied.

#### **2. Energy Performance Enhancement:**

The second step will be concerned with enhancing the energy performance of the building and testing the results using software modelling techniques. The main focus will be on factors affecting heating and cooling loads and thermal comfort of the indoor environment. The building envelope characteristics defined as the facade design and the U-value of the used materials are the basic aspects to be studied as well as the level of insulation of the windows.

#### **3. Renewable Energy Systems:**

Based on the climate data analysis and software modelling, the final step would be determining the renewable energy system to be used. Various computer programs could be used to simulate the energy demand and generation of different renewable sources like TRNSYS, EnergyPlus, Homer and DesignBuilder. The exact number of PV arrays, wind turbines or solar heaters is to be determined in addition to the scheme of connecting the renewable energy system to the grid.

By considering those three steps and combining other strategies from the literature, a guide is produced, and can be described as follows.

### **Proposed guideline**

In this research a specific combination between two approaches: retrofitting approach and nZEB approach is proposed, this is the reason behind mixing the methodologies of the two approaches to generate the novel adequate methodology or

guideline. By calibrating the previously mentioned strategies in the literature and then refining some changes, the hybrid guideline is proposed as seen in figure 5.

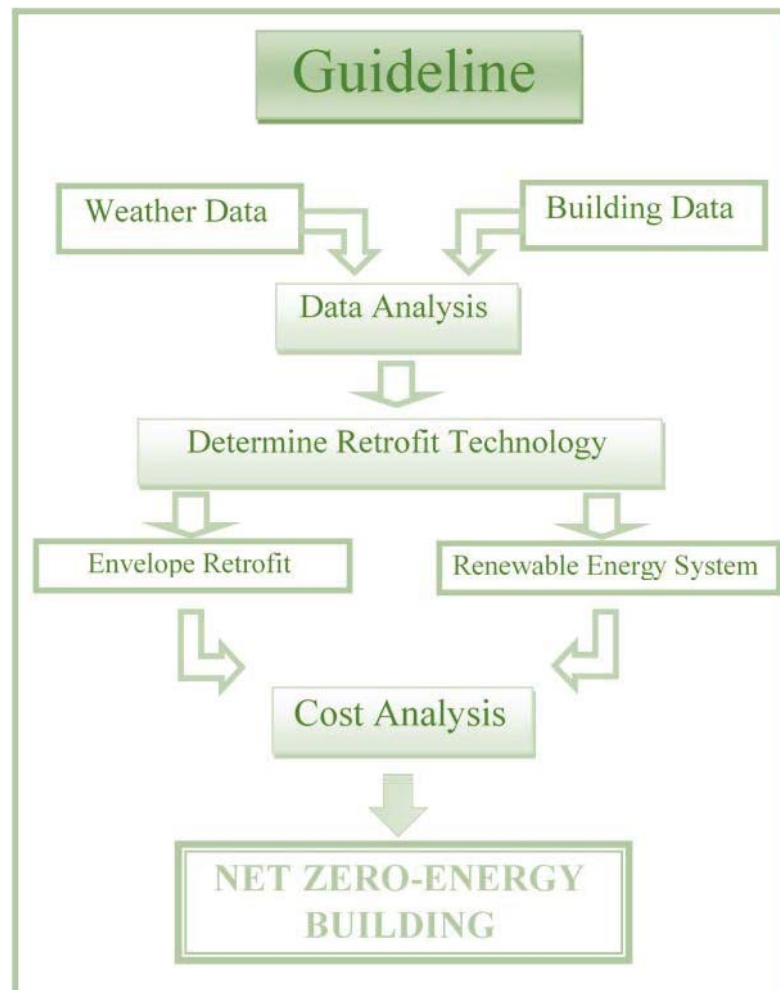


Figure 5. proposed guideline.

### Case study

Implementation of the theoretical study on an existing project gives the chance to the study to develop from being an analytical research to a hands-on experiment. This research will utilize an actual residential building in Nasr City area as its case study. The building has certain energy performance level and needs a certain amount of electricity to perform. If the energy performance could be enhanced and the electricity could be generated through PV panels, then the building can be a zero-energy building. The following section will show the application of the methodology on a step by step basis.

### Weather data

Based on data from the Egyptian Solar Radiation Atlas, the monthly average values of daily global solar radiation are stated in table 1. The results show that the highest intensity values lie in the summer months while the lowest values are in the winter months. Based on a paper that tested actual PV panels installed in Cairo for a whole year with different inclination angles (15 and 30 degrees) and different types of panels concluded that the 30 degree inclination and polycrystalline type is the optimum, based on Cairo's meteorological data (Fayek, 2012).



Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Daily radiation in kWh/m <sup>2</sup> /day	3.18	4.30	5.60	6.68	7.39	8.01	7.93	7.36	6.34	4.93	3.73	2.96

Table 1. Daily solar radiation

### **Building data**

The case study building is a five-storey residential building with two apartments per floor each of an approximate area of 140 m<sup>2</sup> and total surface area of the building is 300 m<sup>2</sup>. The typical floor plan and 3d model for the prototype are as seen in figures 6 and 7 respectively. The building is located in an average residential community in Nasr City area in Cairo.

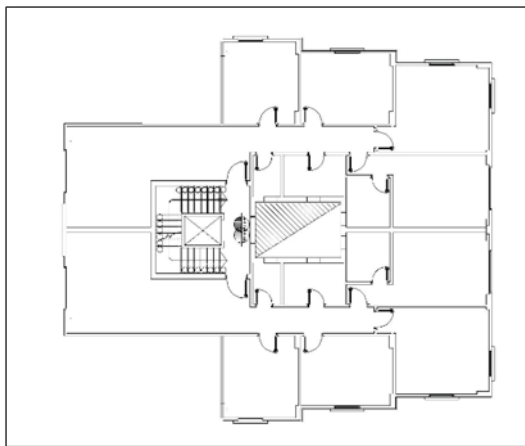


Figure 6. Typical floor plan for case study building

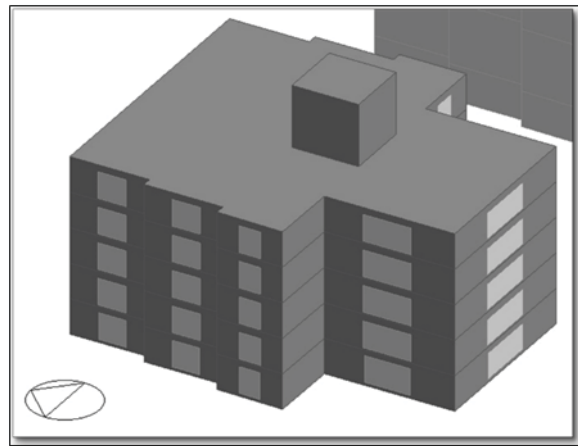


Figure 7. 3D model for case study building

### **Consumption data**

An average consumption monthly rates were detected as seen in figure 8 from the actual electricity bills of the case study building. The total average electricity consumption per apartment is 6,206 kWh/year. In order to calculate the electricity consumption for the whole building, then the 10 apartments have to be considered: 62,060 kWh/year approximately 62,000 kWh/year.

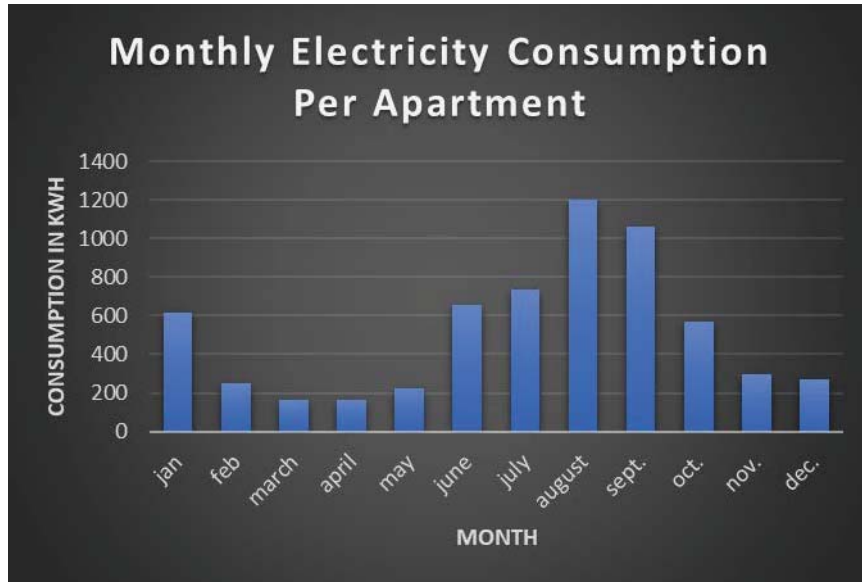


Figure 8. Monthly electricity consumption per apartment in the case study building – 2015

### Envelope analysis

The building's vertical envelope is a single wall of 25 cm thick bricks, having aluminium framed windows. No insulation is installed in the outside or the inside of the envelope. The roof layering is the finishing tiles, the waterproofing membrane, the thermal insulation, and then the concrete slab that is covered by plaster from inside.

By analysing the data provided in the previous section and through visual investigation, it was found that the building's energy performance can be categorized as poor due to the following:

- The building is only insulated by the traditional thermal insulation on the roof of the top floor –as provided by the owner.
- There is no shading over the windows to prevent direct sunlight from entering the interior space.
- The windows are single glazed.
- The windows are leaking, so the amount of heat energy transferred from the outside to the inside is significant.
- The HVAC system is split system not central, and mostly in a moderate condition.

### Envelope retrofits

Based on the data analysis of the building's energy performance, the retrofit technologies that compensate for the inefficiencies of the current building status could be proposed as follows:

#### 1. Window Type:

Before choosing the best window type, a comparison between different options was considered as follows:

Window type	Single	Double	Triple
U value (W/m <sup>2</sup> K)	7.24	2.43	Not specified
Price (LE/m <sup>2</sup> )	700	1200	Not available
Best option		★	

Table 2. Comparison between different window types ('01.Building Efficiency Improvement Code Part 1 Residential Buildings (code 306-1).pdf (in Arabic)', 2006)

Accordingly, the windows will be replaced with double glazed aluminium framed windows with clear glass. The window section is composed of 6mm glazing on each side, separated by 10mm air space. The total glazing area was calculated to be 120 m<sup>2</sup>, as every apartment has 6 windows: 4 (1.5x1) and 2 (2.5x1.5). So, the total glazing area for one apartment is 12 m<sup>2</sup>, which equals 120m<sup>2</sup> for the 10 apartments. Based on field research, the price of the previously mentioned window section ranges from 1100-1300 LE/m<sup>2</sup>.

### 2. Window Coating:

There are different types of coating available, a comparison between the most appropriate types as stated by the manufacturer included the external reflection percentage of the film that represents the amount of privacy preserved for the users (Films, 2015). Similarly, the total solar energy rejected by the film is considered, and finally its price:

Film type	Silver 20	Prestige 70	High vision 25
Exterior visible reflection	58%	9%	20%
TSER (total solar energy rejected)	77	50	60
Price (LE/m <sup>2</sup> )	268	582	361
Best option	★		

Table 2. Comparison between different glass film types

The overall area to be covered by the film is calculated by subtracting the aluminium frame area from the previously calculated window's area. Knowing that the frame's thickness is 5 cm, then the net area of the glass is 102m<sup>2</sup> for the whole building.

### 3. Wall Insulation:

According to a study that compared different finishing materials with their U-values - a measure of the heat transmission through a given material with lower numbers indicating better insulating properties- the different cladding materials were compared in table (5-4) (Georgia, 2014). By adding the prices in the Egyptian market to the comparison chart, the next results were found:

Cladding type	Gypsum board	Marmox board	Wood cladding
U-value	0.6	0.19	0.34
Price (LE/m <sup>2</sup> )	100	95	500
Best option		★	

Table 3. Comparison between different cladding options

To calculate the quantity of tiles needed for the wall cladding, the circumference of the building is multiplied to the total building height -assuming that the material will be installed on the outside of the building. The total area to be covered is 18x15= 1,275 m<sup>2</sup> then the windows' area is subtracted to have the net area = 1,275- 120 = 1,115 m<sup>2</sup>. The price per m<sup>2</sup> is 64.7 LE according to the supplier's offer.

#### 4. Roof insulation:

The tiles too be used for roof insulation are 30x30 cm and thickness (2-5cm), its water absorption by submerging is negligible, and this is why it is suitable for rooftops. It is available in plain grey color or patterns. Can be easily installed using cement mortar. All the needed data are found on the reference (Tilefoam, 2015). This material is characterized by its high thermal resistance from what reflects on its energy saving potential as seen in table (5-6). The overall area of the roof to be covered by the Tilefoam is calculated to be 309 m<sup>2</sup> after subtracting the stair room. The market price for the Tilefoam is 65 LE/m<sup>2</sup> from CMB.

#### Simulation

For the retrofit actions to be verified, energy simulation needs to be performed. Using DesignBuilder software the electricity consumption of the existing building with its current situation is done. The retrofit actions are then simulated in order to be able to measure the difference in electricity consumption between the two cases. The daily simulation of the current status of the building showed great resemblance to the actual electricity consumption of the building that is provided by the actual electricity bills.

After considering the envelope retrofit actions the annual electricity consumption is decreased to 44000 kWh instead of 66000 kWh in the current existing case. This shows the impact of the retrofit technologies used and gives a base for the PV system design to work on. Figure 9 shows the results of the annual simulation for the retrofitted case study building.

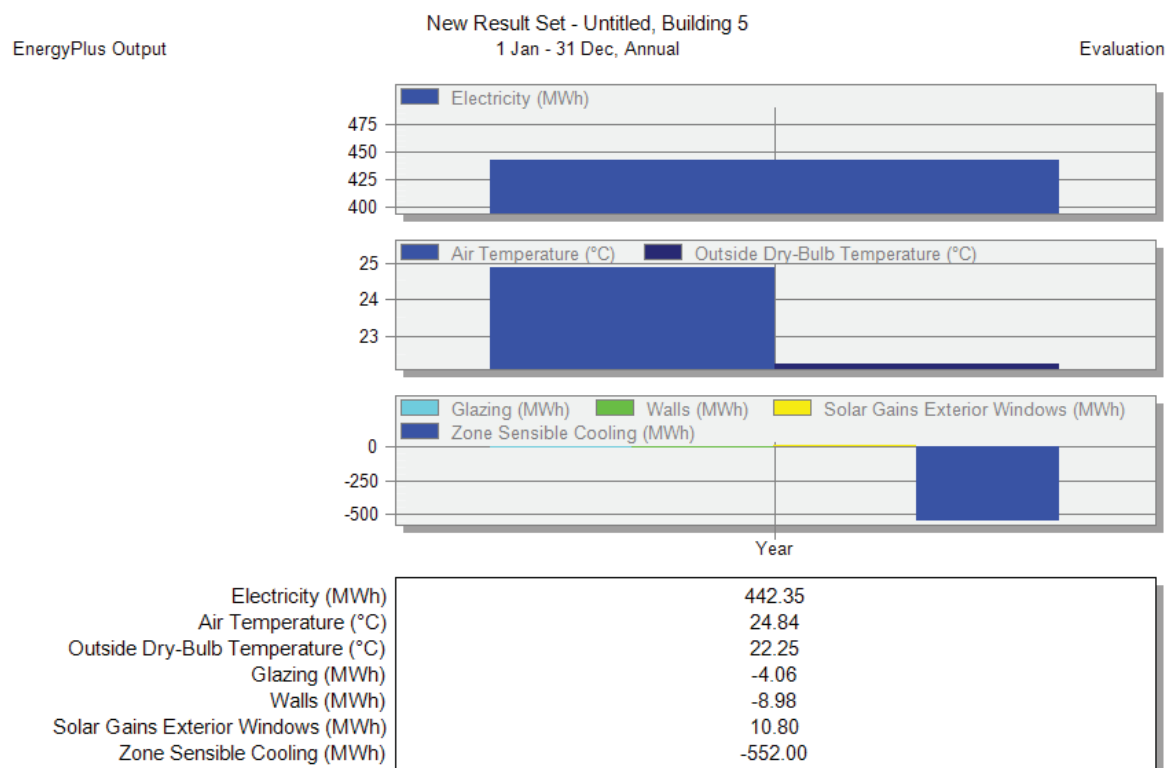


Figure 9. Retrofitted case annual simulation

#### Renewable energy system

For the PV system to be calculated, the amount of electricity resulted from the simulation is used (44,000 kWh). Knowing that every 1 kW power station generates 1800 kWh/year, then the building will need a 24-kW station (44,000/1800). As stated by the supplier, for each 1 kW power station 4 panels and a surface area of 10 m<sup>2</sup> of plane roof is

needed and it will cost 10,000 LE ('Cairo Solar', 2015). By doing the calculations, the 24-kW station will need 240 m<sup>2</sup> of roof area (24x10), which is available for the case study building.

#### **PV system installation data**

- The panels' orientation: panels will be installed facing south direction based on the solar data analysis provided previously.
- The panels' inclination angle: will be 30 degrees.
- Type of panels will be poly crystalline type because it generates the largest amount of energy in the Egyptian circumstances.
- The spacing between panels in order to avoid surplus shading of the panels on each other was calculated that if the tilting angle was 30 degrees, then a space of 60 cm must be between each row of panels and the one proceeding it.

#### **Conclusion**

Existing residential buildings in Egypt suffer from low insulation levels from which increases the energy consumed to reach the thermal comfort inside the building. A possible solution for this problem is to convert existing buildings to Net Zero-energy buildings. The study analyzes the possibility of implementing this solution on the Egyptian context. After studying the energy situation in Egypt as well as the existing building energy performance, the nZEB concept is studied as a possible solution. The empirical part of the study provides a guideline to be followed to reach this goal. Then this guideline is applied on a hands-on case study building in order to test its feasibility. Simulation is used to evaluate the effectiveness of the retrofit actions, and was found to decrease the electricity consumption by one third. A PV station is then designed to cover for the rest of the electricity consumed by the building.

The results of the study reveal that an existing residential building can be converted to a Net Zero-energy building using the proposed guideline. The cost analysis implemented in the study reveals the exact costs of both the retrofit actions –using materials existing in the market- and the PV panels' installation and it was found to be affordable.

#### **Bibliography**

'01.Building Efficiency Improvement Code Part 1 Residential Buildings (code 306-1).pdf (in Arabic)' (2006).

Attia, S. (2013) *A Tool for Design Decision Making, Design Decision-Making - Volume 1 - Computation and Performance eCAADe* 31. Available at: [http://cumincad.architecture.net/system/files/pdf/ecaade2013\\_003.content\\_0.pdf](http://cumincad.architecture.net/system/files/pdf/ecaade2013_003.content_0.pdf).

Attia, S., Evrard, A. and Gratia, E. (2012) 'Development of benchmark models for the Egyptian residential buildings sector', *Applied Energy*. Elsevier Ltd, 94(2012), pp. 270–284. doi: 10.1016/j.apenergy.2012.01.065.

'Cairo Solar' (2015) *PV grid systems*, pp. 5–6.

Deng, S., Wang, R. Z. and Dai, Y. J. (2014) 'How to evaluate performance of net zero energy building - A literature research', *Energy*. Elsevier Ltd, 71, pp. 1–16. doi: 10.1016/j.energy.2014.05.007.

Eehc (2015) 'Annual Report 2013/2014', p. 56. Available at: [http://www.moe.gov.eg/english\\_new/EEHC\\_Rep/REP-EN2013-2014.pdf](http://www.moe.gov.eg/english_new/EEHC_Rep/REP-EN2013-2014.pdf).

Fayek, H. H. (2012) 'Comparative Study for Performance of different kinds of PV cells at



different working and environmental conditions’.

Films, W. (2015) ‘Energy costs’, p. 313.

Garde, F. *et al.* (2014) ‘Design of Net Zero Energy Buildings: Feedback from International Projects’, *Energy Procedia*. Elsevier B.V., 61(November 2008), pp. 995–998. doi: 10.1016/j.egypro.2014.11.1011.

Georgia, U. (2014) ‘Resistances and U-values for typ walls and roofs’. Available at: [http://www.caes.uga.edu/departments/bae/extension/handbook/documents/Resistances and U-values for typ walls and roofs.pdf](http://www.caes.uga.edu/departments/bae/extension/handbook/documents/Resistances%20and%20U-values%20for%20typ%20walls%20and%20roofs.pdf).

Ibrahim, a. (2012) ‘Renewable energy sources in the Egyptian electricity market: A review’, *Renewable and Sustainable Energy Reviews*. Elsevier Ltd, 16(1), pp. 216–230. doi: 10.1016/j.rser.2011.07.149.

‘NREA’ (2015). Available at: <http://www.nrea.gov.eg/english1.html>.

Pérez-Lombard, L., Ortiz, J. and Pout, C. (2008) ‘A review on buildings energy consumption information’, *Energy and Buildings*, 40, pp. 394–398. doi: 10.1016/j.enbuild.2007.03.007.

*Potential of solar thermal energy* (2015). Available at: <http://www.statista.com/statistics/269522/potential-of-solar-energy-in-the-middle-east-and-north-africa/> (Accessed: 1 April 2015).

Sartori, I., Napolitano, A. and Voss, K. (2012) ‘Net zero energy buildings: A consistent definition framework’, *Energy and Buildings*. Elsevier B.V., 48, pp. 220–232. doi: 10.1016/j.enbuild.2012.01.032.

Sun, Y., Huang, P. and Huang, G. (2015) ‘A multi-criteria system design optimization for net zero energy buildings under uncertainties’, *Energy and Buildings*. Elsevier B.V., 97, pp. 196–204. doi: 10.1016/j.enbuild.2015.04.008.

Szalay, Z. and Zöld, A. (2014) ‘Definition of nearly zero-energy building requirements based on a large building sample’, *Energy Policy*. Elsevier, 74, pp. 510–521. doi: 10.1016/j.enpol.2014.07.001.

Tilefoam (2015) ‘tilefoam’.

Wang, L., Gwilliam, J. and Jones, P. (2009) ‘Case study of zero energy house design in UK’, *Energy and Buildings*, 41, pp. 1215–1222. doi: 10.1016/j.enbuild.2009.07.001.

# **Towards Advanced Active Façades. The development and assessment of a new façade concept, which combines passive and active design strategies.**

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**Abstract:** In Switzerland, as in many European countries, new energy directives focus on decreasing the carbon footprint of buildings by promoting passive and active energy strategies and systems. Among the latter, Building Integrated Photovoltaics (BIPV), which function both as envelope materials and electricity producers, are rapidly improving their performance. However, their potential remains largely unrealised due to diverse barriers. Among them, the poor expressive qualities of many BIPV products are preventing architects from using these systems. In reaction, and with the goal of bridging the gap between technology and designers, a new façade concept has been developed integrating BIPV expressive issues. This is the Advanced Active Façade (AAF) concept, which results from analysing the evolution of façade requirements and solutions over time. The AAF combines passive and active façade design strategies. This is to say; it simultaneously aims to achieve low embodied energy by benefiting from passive low-carbon design strategies, and to generate energy by integrating BIPV technology. The AAF construction system is the direct application of the AAF concept to construction practice. It is a wood-based, self-supporting and demountable façade system, which meets the most exigent insulating targets and is compatible with a wide range of existing BIPV formats and emerging technologies. The development of this system is paired with a series of design strategies which present a variety of scenarios where the AAF concept can be applied. In addition, this concept is assessed regarding its environmental impact, cost and architectural quality.

The AAF construction system and design strategies have provided the basis for realizing a real scale active prototype. Ultimately, the output of the research will provide architects with a system and assessed design strategies to optimize design process of BIPV façades, meeting the new energy directives performance standards.

**Keywords:** Building Integrated Photovoltaics, Low-carbon façades, Design Strategies, Energy efficiency

## **Research overview**

The European Union is committed to drastically reduce greenhouse gas emissions by 2050: levels should be 80-95% lower when compared to 1990 (Energy Roadmap 2050, 2012). This is why European energy directives are becoming more demanding with regards to performance standards. Switzerland follows the same evolution. Since it decided to gradually withdraw from nuclear power in 2011 (SFOE, 2014), the country undergoes a profound restructuring of its energy system. Its new energy policy establishes that energy consumption from photovoltaic (PV) will represent 20% of the total electricity consumption of the country. Thanks to this energy focus, such technology is becoming more efficient and affordable.

The most innovative offer of PV technology consists in the constructive and architectural integration of PV elements. This technology is named Building Integrated Photovoltaics (BIPV) and have both an architectural function and energy generation capacity.

BIPV permits to reduce material use and initial investment costs when compared to a traditional construction where PV systems are independent and added to the building (Centre Suisse de compétence BIPV, 2015). However, despite this favourable context, BIPV technology is not exploited to the best of its potential. Architects often justify the lack of PV use in their designs with the limited aesthetics of existing BIPV solutions. As a result, a real

gap between technology and architecture exists. This evidences that further research is needed in order to bridge this gap between technology and designers.

Targeting bridging this gap, a new facade concept has been developed in order to approach architects to BIPV technology and energy efficiency concepts. This façade is called Advanced Active Façade (AAF) due to the combination of passive and active energy design strategies. The concept is materialized in façade construction system and the correspondent facade design strategies, which can be assessed easily with methods and a language that architects can easily understand. The development of the AAF narrows the gap between technology and designers due to the use of architectural language for communication and a solid assessment, not only based on energy performance but also architectural quality, environmental and economic impact of the facade.

### **Research approach**

In order to deal simultaneously architectural, construction and technological issues, the research approaches the subject based on a reinforced collaboration of product developers, architects and scientist. To fill in the gap between these agents, new design strategies are developed for the composition and construction of active façades.

The work developed in this research focuses on collective residential buildings in the Swiss context. This target is a consequence of a preliminary analysis of BIPV buildings' state of the art world wide (Clua Longas et al., 2015). This analysis showed a scarcity of dwellings among the best-practice selection, which is mainly due to the high cost and lack of knowledge of developers and architects (Farkas and Horvat, 2012). This research will enable architects and the general public to deepen in BIPV façade composition and construction knowledge, as well as motivate them to integrate BIPV in their designs.

The approach of the research is based on the analysis of different factors that affect BIPV façades. These preliminary analyses set a common ground to the already mentioned product developers, architects and scientist, which permits a more efficient collaboration to the development of the AAF concept. The outcome of these preliminary analysis enables the application of the theory to the practice by architectural design. Once there is an architectural product output that can be assessed, different criteria will be evaluated. The criteria will assess architectural features as well as energy performance values. In a fourth step, a real scale prototype has been constructed in order to test and verify different aspects of the façade concept. The presentation of the prototype in a national architecture forum has also introduced the last step: the knowledge transfer phase. This last phase consists mainly in a student competition, which permits testing how architects use and appropriate the design strategies and architecture concepts developed on the research process. Figure 1 shows a schematic research methodology to illustrate the research approach.

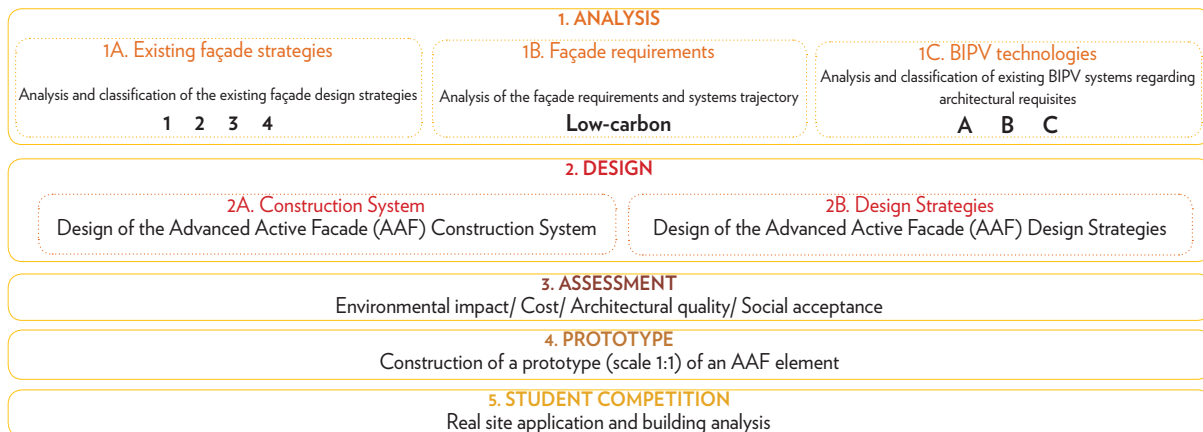


Figure 1. Research methodology in five phases

## Research outcome

Following the methodology explained above, the preliminary results of the research can be classified according to the different research phases.

### Analysis

The Advanced Active Façade concept is based in three analyses. The first one refers to the Swiss residential building common practice façade composition. Different elements take part in the façade composition process: building's structure, windows, balconies, doors, etc. (Herzog et al., 2004). These element's dimensions determine the subjacent grid or rhythm of the façade composition. The first phase of the research consists in analysing and classifying the existing façade design strategies.

The output of this first phase manifested that existing façade design strategies can be classified: four categories have been the outcome of the analysis (figure 2).

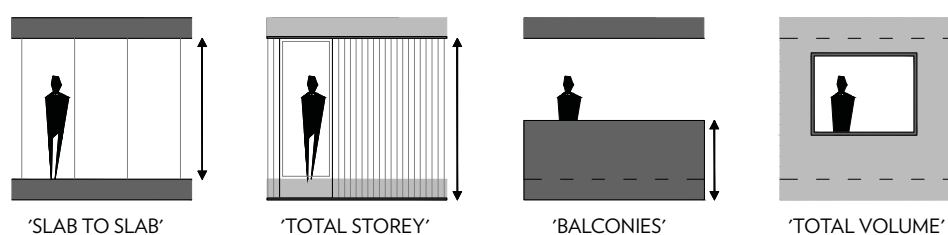


Figure 2. Collective residential buildings' façade design strategies: classification in four groups

The 'Slab to Slab' strategy includes façades where the horizontal structure of the building is apparent and the dimension of the horizontal slab is highlighted on the façade. The 'Total Storey' group gathers façade designs where the building horizontal structure is also expressed, but the resulting dimension is that of the whole storey, which does not show the horizontal slab. The third strategy, 'Balconies', refers to façades where balconies are clearly apparent in a large part of a façade. The consequence is that the balcony dimension predominates in the façade composition. Finally, the 'Total Volume' group includes façades where the structure rhythm and the interior distribution are not apparent. Many buildings present a combination of these four strategies in the same façade or in different ones.

This classification is both useful for architects and product developers. The former can identify easily different façade elements with different dimensions. Then, architects can

evaluate which of those will be active and which will not, depending on different energy strategies explained in the 'Assessment section'. Product developers can find in this classification different dimensions with standardization potential, which will decrease BIPV production costs.

The second analysis carried out on this research refers to the evolution and trajectory of the façade requirements and the solution systems developed to meet those requirements. In the beginning, wood and stone huts façades only needed to protect from the environment. Currently and in the near future, façades need to lower the building's final energy consumption, they will be required to have a very low embodied energy and to generate energy. These three requirements have find different solutions in façade construction, but there is not yet a widespread façade system that meets all three requirements. This is mainly due to the different professionals and specialist that deal with passive and active energy strategies.

Finally, a third analysis classifies the existing BIPV systems. There is a growing number of different PV technologies as research is rapidly pushing forward this field (Jelle et al., 2012). And BIPV systems have been already classified in many different ways. The originality of our approach is that BIPV façade systems are classified according to its architectural features given that they play an important role as an integral part of the façade (Roberts and Guariento, 2009). Therefore, existing systems have been classified, based on their transparency degree, in three groups (Clua Longas et al., 2017): Opaque, Translucent and Transparent. Different technologies such as monocrystalline, polycrystalline or thin-film can fit in one or more of these categories, depending on their disposition on the BIPV module. This classification is open and welcomes the newest high efficiency modules such as heterojunction technologies, which combines two layers of different crystalline semiconductors, or organic cells, among others.

## ***Design***

The previous analyses set the basis for the development of the Advanced Active Façade (AAF) concept, which combines active and passive energy design strategies. It consists on an active BIPV façade, which is combined with highly insulated low-embodied carbon construction. This approach respond to the existing design strategies at the façade composition level, it also meets the latest façade requirements analysed and welcomes a large variety of BIPV systems. The AAF is a concept that can lead to design Nearly Zero Energy Buildings (NZEB) when combined with other passive and active energy building strategies, regarding building services and structure design.

The AAF is designed as a non-structural, self-supporting façade, which guarantees more flexibility in the façade composition compared to other loadbearing options. Based on this concept, the AAF Construction System and the AAF Design Strategies have been developed.

### ***Advanced Active Façade Construction System***

The AAF Construction System is the materialisation of the AAF Concept (figure 3). Hence it has a very low thermal transmittance value, follows low-carbon construction principles and integrates BIPV.

In the Swiss context, the most exigent normative regarding building's insulation is Minergie P. The AAF construction system, with a total of 400 milimeters of two different insulators in two different layers, achieves a  $0.1 \text{ W}/(\text{m}^2\text{K})$  thermal transmittance value, which meets also Passive House standards.



The embodied carbon of a building accounts approximately for 30% of the total lifetime carbon footprint from the residential building sector (Lane, 2010). More specifically, façades are responsible for around 16% of the embodied carbon of a building (Cheung and Farnetani, 2015). For this reason, a low-carbon façade construction system can make a significant difference in a building's total carbon footprint.

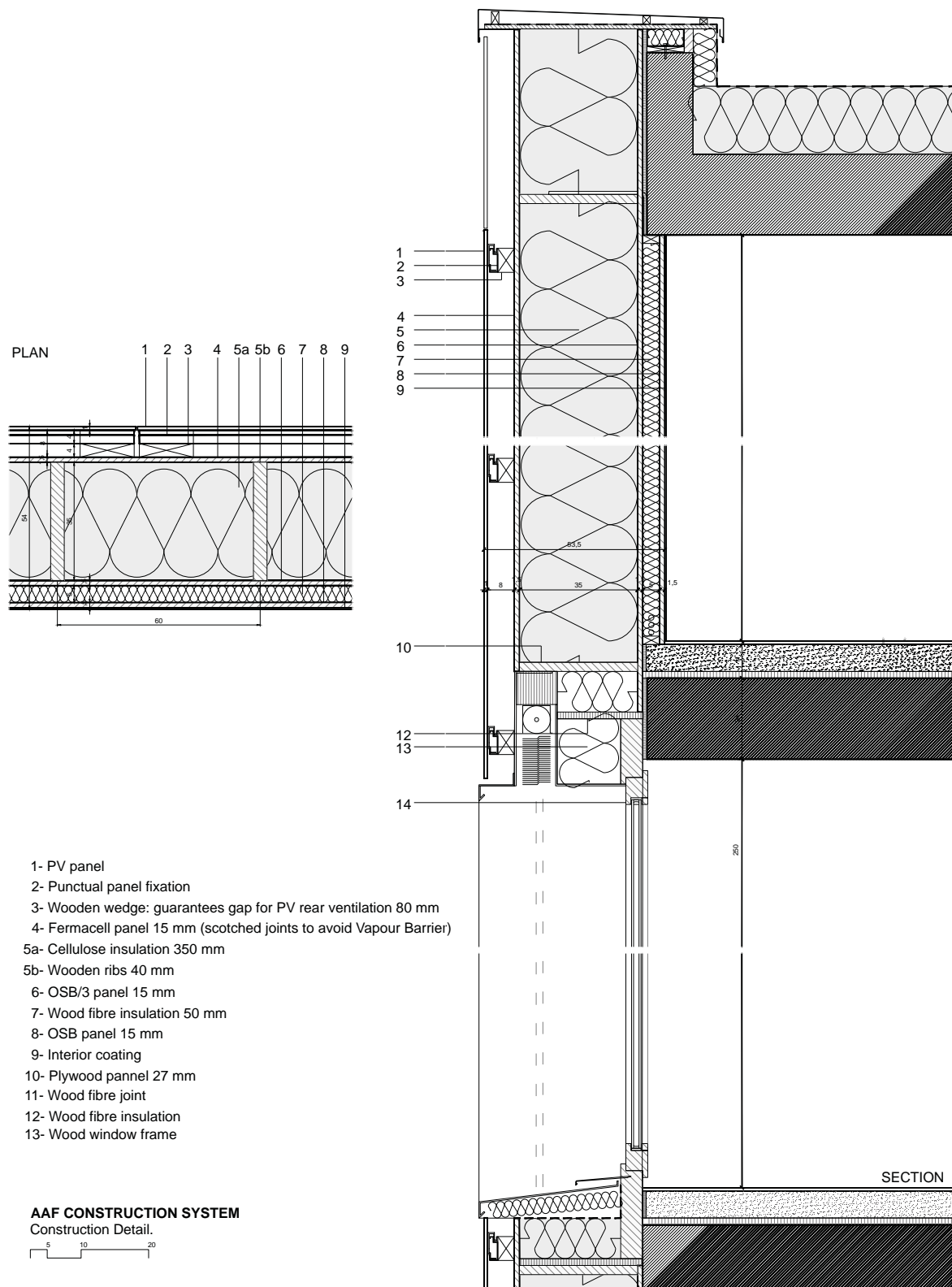


Figure 3. Advanced Active Façade construction system

The AAF construction system (Fig. 3) follows the low-carbon construction principles among we highlight the following: Using of natural, locally-sourced materials; reducing material's amount throughout the entire life cycle; designing the system to be disassembled rather than demolished (this involves the use of bolts instead of adhesives), designing a prefabricated system with low maintenance, designing a recyclable system with reusable materials. These principles have led to a light wood-framed prefabricated construction system, with two layers of natural insulation: cellulose and wood fibre.

The integration of BIPV in a façade involves a ventilated façade, with a ventilated chamber of 80-100 millimeters to guarantee the rear ventilation of the BIPV panels (Brinkworth and Sandberg, 2005). Among all sorts of PV panel layering composition, the AAF constructions system integrates glass-glass BIPV panels, which permit a frameless panel composition. Among the fixing options, the system works with invisible ones: one option is the punctual metallic fixations and a second option is the linear metallic fixations, adherer to the rear of the BIPV panels.

#### *Advanced Active Façade Design Strategies*

It exists a number of researches which have already studied solar systems integration and have provided composition guidelines: IEA - SHC, 2013, FOSTer inMED, 2015, Munari Probst et al., 2012. They mainly focus on the functional integration and some construction guidelines. Some of them also propose visual simulations of existing façades and how they can integrate solar systems.

This ongoing research aims to develop a number of scenarios that widely represents common practice in the Swiss context. This will permit every architect, independently from style, land situation or urbanistic constraints, to find solutions or inspiration to BIPV façade composition. In addition, different criteria assessments will permit architects to evaluate themselves the optimal example for their practice.

To develop real scenarios, the 'Standard Swiss Dwelling' has been identified and adapted to a real site in Lausanne. In the context of urban densification, a land with a building in demolition process has been selected in Lausanne. This city has the representative climatic conditions of the "Swiss plateau", where most of the Swiss population lives. The standard building typology and climatic conditions of the site, permit a wider application of the design strategies to particular case studies in the rest of Switzerland and potentially in central and southern Europe.

The Advanced Active Façade design strategies are applied to the 'Standard Swiss Dwelling' in Lausanne. They are the combination of the four existing design strategies ('Slab to Slab', 'Total Storey', 'Balconies' and 'Total Volume') with the three groups of BIPV systems (Opaque, Translucent and Transparent) identified in the analysis phase. This combination results in 12 scenarios which integrate BIPV.

Figure 4 gathers four images which represent four of the twelve real site scenarios. This sample represents all four designs strategies combined with three different BIPV systems. The first AAF design strategy (1A) presents a BIPV system recently developed in Neuchatel by CSEM researches. It has opaque BIPV modules composed by monocrystalline cells and a grey metal mesh filter which gives colour, texture and vibrant reflections to the façade. These modules generate around  $120\text{W/m}^2$ . The second design strategy (2B) integrates translucent BIPV modules in sliding panels for solar control purposes on the balconies. These translucent panels generate also  $120\text{W/m}^2$ . The third image (3C) has transparent BIPV balconies in its south façade. The transparent thin-film modules generate around  $50\text{W/m}^2$ . The fourth image (4A) has opaque high efficiency perovskite modules which generate  $270\text{W/m}^2$ .



Figure 4. AAF Design Strategies sample

## Assessment

Both the AAF Construction System and the AAF Design Strategies are assessed following different criteria: Environmental impact, social acceptance, architectural quality and cost.

### Environmental impact

Regarding environmental impact, the Life Cycle Assessment (LCA) of the AAF construction system has been studied. Its preliminary results have been compared to Swiss common practice construction system LCA, and Swiss best practice LCA (Fig. 5). The AAF construction system presents a remarkable difference regarding the embodied energy of its structure. Although the total embodied energy is higher due to the high embodied energy of BIPV panels, it is largely compensated by the energy that they generate.

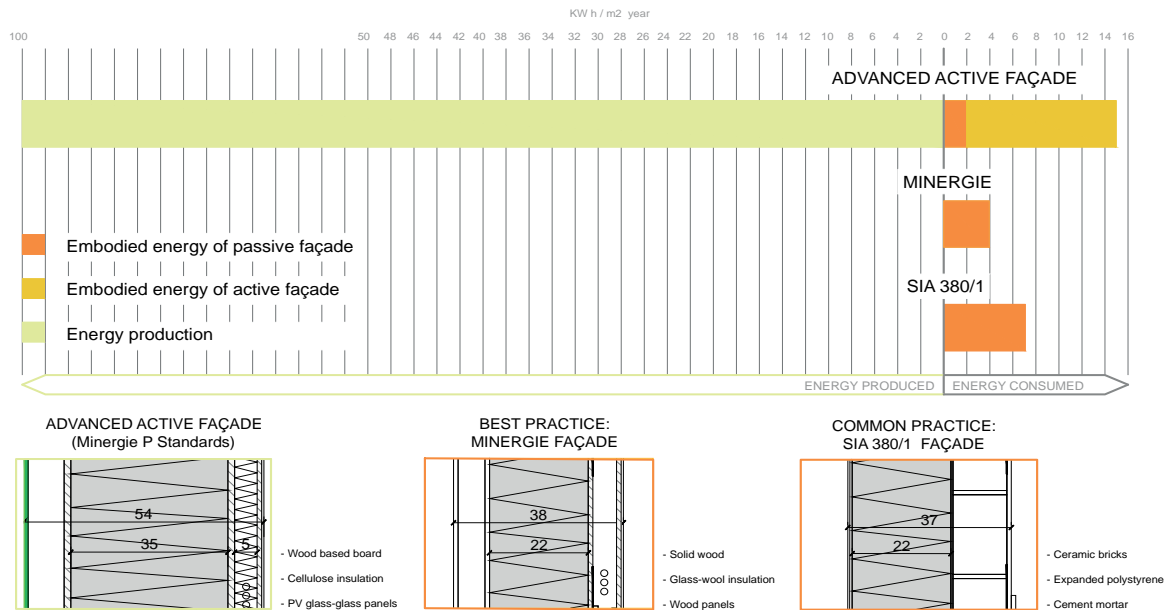


Figure 5. Life Cycle Analysis comparative: Advanced practice: AAF Construction system, Best practice: Minergie facade and Common practice: SIA 380/1 façade

To assess the Environmental impact of the Design strategies, the scenarios have been simulated using a building simulation tool (Design Builder). Different criteria such as total energy generation, self-consumption, self-sufficiency and energy exceed are displayed in the graphics (Fig.6), to provide architects with all the information they might need to target different objectives.

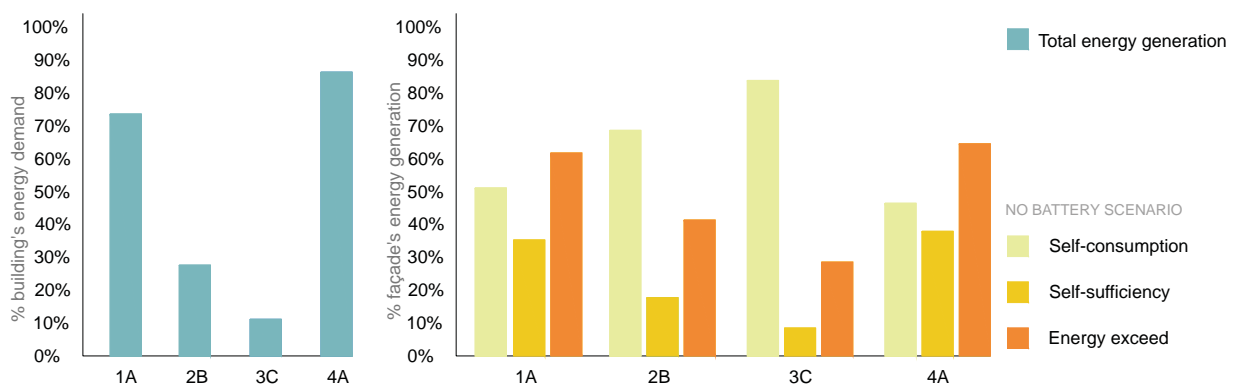


Figure 6. Energy simulation results. Refers to scenarios illustrated in figure 9

When designing a BIPV façade, there are two main active design strategies to consider, regarding energy production. On one hand, when the objective is to maximize the autonomy of the building, the design must prioritize a high self-sufficiency percentage. On the other hand, to minimize the energy injection to the grid, façade design should prioritize a high self-consumption percentage. Figure 7 and 8 illustrates these concepts by showing the example 1A simulations in two different times of the year: January and June.

The areas A and B are the total net electricity demand and generation, respectively. The overlapping part in area C is the PV power that is utilized directly within the building. This is sometimes referred to as the absolute self-consumption. What is most commonly meant by

self-consumption, however, is the self-consumed part relative to the total production, which in the simplified nomenclature of Fig X would be:  $\text{Self-consumption} = C / (B+C)$

The self-consumed part relative to the total load is also a commonly used metric. Normally we refer to it as self-sufficiency:  $\text{Self-sufficiency} = C / (A+C)$

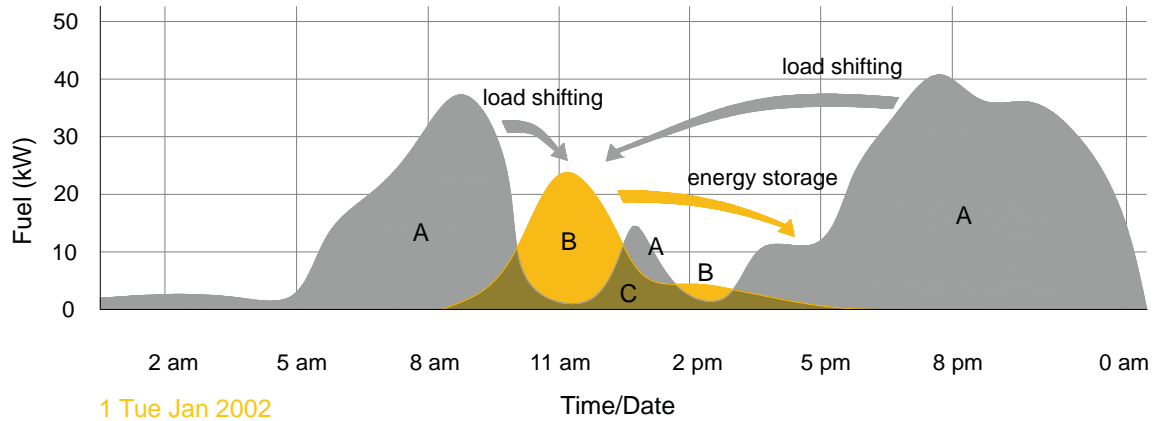


Fig 7: Schematic outline of daily net load (A+C), net generation (B+C) and absolute self-consumption (C) in a building with on-site BIPV (Design Strategy 1A example). It also indicates the function on the two main options (load shifting and energy storage) for increasing the self-consumption. In a winter scenario

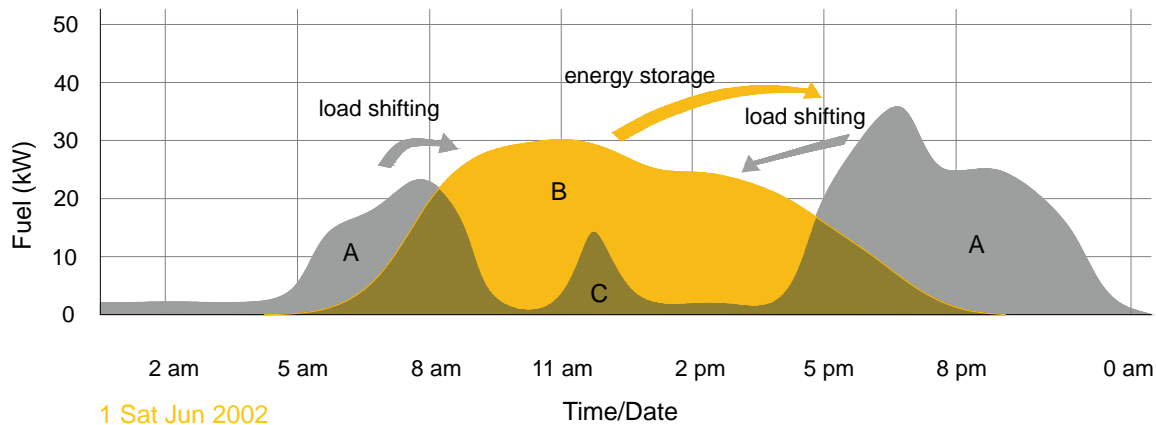


Fig 8: Schematic outline of daily net load (A+C), net generation (B+C) and absolute self-consumption (C) in a building with on-site PV (Design Strategy 1A example). It also indicates the function on the two main options (load shifting and energy storage) for increasing the self-consumption. In a summer scenario

Since the output of PV power is determined by variable meteorological processes, solar generated electricity cannot be reliably dispatched or perfectly forecasted. Additionally, in residential buildings, the PV generation and electricity consumption do not have the same variation profile. As shown in figure 6, this mismatch brings the need to export to the grid a significant part of the locally generated energy, even though energy is later imported from the grid (Vieira et al., 2016). For this reason, the integration of an energy storage system seems interesting to improve the self-consumption of the PV installation. With a storage system, the excess PV electricity during the day is buffered and later used at night. In this way, households equipped with a PV battery system can reduce the energy drawn from the grid and therefore increase their self-sufficiency.

The widely-employed method to improve PV performance is to incorporate batteries. Today it is still expensive for most households but due to its price drop: ca. 14% annually from



2007 to 2014 (Zhang et al., 2015) and its steep learning curve (paired to electric mobility research) it is foreseeable that in a near future all BIPV buildings will count with a battery system.

### *Social acceptance*

In collaboration with ZHAW Zurich University of Applied Sciences, a public survey has been carried out to assess the social acceptance of the AAF design strategies developed. The main conclusion is that most respondents are in favour BIPV integration in Switzerland, and more that 70% percent of the respondents are convinced to use BIPV in their neighbour. It was revealed that the public believes that BIPV use increases the reputation the site and buildings which integrate it. It was also relevant to find out that the public gives more importance to color and design than to efficiency and electricity production. This finding reinforces the reasons and focus of the on-going research which is dealing with BIPV architectural features and expressive issues.

Further assessment regarding architectural quality and cost is currently being developed in collaboration with experienced architects of the Swiss context and façade constructors.

### **Prototype**

Collaborating with BIPV producers, wood façade experts and Swiss façade consultants, a prototype of the AAF façade has recently been constructed. It consists in a demonstrator of the AAF construction system and the latest BIPV panels produced by CSEM (Fig.9). This exercise has permitted to test how professionals from very different backgrounds can work together with a common objective: a successful BIPV façade. This goal, which was stated at the beginning of this paper, is one of the main targets of our research. The prototype design and construction process has also permitted to verify the prefabrication potential of the construction system with the façade constructors. Working with experienced façade consultants has permitted to optimize material quantity, as well as the fixation systems

The CSEM laboratory has handmade the BIPV modules displayed on the prototype. They consist in a frameless encapsulation of regular PV monocrystalline cells, with a superposed metal or glass fibre mesh. This extra layer, integrated in the module structure, gives them texture, colour and dynamic reflections. These architectural qualities open a new horizon for BIPV ventilated facades. However, this extra layer blocks part of the sunlight from the cells, this is why the efficiencies of these panels are slightly lower than regular panels. While a standard BIPV panel has 18% efficiency, these panels' efficiency varies among 9% and 15% depending on the mesh material, density and structure. According to the research team, as cells' performance is improving, we can tolerate some loses in performance in favour of a better expressive quality of the BIPV module. This compromise will motivate more architects to use BIPV in their projects. In other words, eventually there will be modules with a lower production, but in a much bigger number which will lead to higher production.

The prototype was presented in the Ecoparc Forum, held in Neuchatel in September 2017. In this event, topics of solar energy generation in the urban context were discussed. During the presentation, the audience, which was mainly architects and investors manifested a high interest on this new BIPV facade: The Advanced Active Façade. An online survey is being carried out to register feedback and optimize the final AAF construction system and design strategies integrating their comments.



Figure 9. AAF full scale prototype. The prototype design allows to understand its composition and the way BIPV panels can be integrated in a low-carbon façade.

### Research preliminary conclusions

With the aim of demonstrating how BIPV can be used as a real construction material in building envelopes, this research proposes a solution that can narrow the gap between technology and architecture. The preliminary results exposed in this paper permit concluding that it is, in fact, possible to integrate different types of BIPV systems into Advanced Active Façade. Firstly, it has been demonstrated how BIPV can be part of the dimensional composition of collective residential housing. The development of this argumentation provides BIPV producers with a series of dimensions and guidelines to consider. This will increase architect's demand and facilitate the BIPV façade composition process. Secondly, collaborating with wood construction experts and façade consultants while developing the construction system, gives the results technical accuracy and reliability. It can be stated that provided with the Advanced Active Façade Design Strategies, architects are enabled to deal with the expressive and aesthetical aspects of their BIPV designs, producing façades fitting the current composition trends in the Swiss context.

The assessment phase demonstrates that regarding environmental impact, the AAF construction system has a lower total embodied energy than any other construction system in the Swiss practice. In addition, the AAF Design Strategies assessment has evidenced that there are different criteria to consider when designing a façade: a building envelope will not be the same if self-consumption is targeted or self-sufficiency shall be maximized. The actual results insinuate the advantages of a BIPV installation while paired with a storage system.

Both LCA and energy demand assessments need further research for simulating building energy performance paired with an energy storage system. To complete the assessment, a collaboration with a BIPV façade constructor will permit to develop an economical comparative of different construction systems generalized in the Swiss context. A prediction comparative will also be provided taking into account the drastic price drops that BIPV and battery storage systems are experiencing.

The next and final step of this research consists in the organization of an international student competition to validate the user-friendliness and convenience of the approach for architects in the practice. This last phase will also initiate the duty of knowledge transfer of our research project.

## Acknowledgments

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## References

- Brinkworth, B.J., Sandberg, M. (2005). Design procedure for cooling ducts to minimise efficiency loss due to temperature rise in PV arrays. *Sol. Energy*.
- Cheung, L., Farnetani, M. (2015). Whole-life carbon: Façades. *Building*.
- Clua, A., Rey, E., Lufkin, S. (2015). PV 2050 BIPV Best-Practice Catalogue. EFPL I LAST.
- Clua Longas, A., Lufkin, S., Rey, E. (2017). Towards Advanced Active Façades: Analysis of façade requirements and development of an innovative construction system. Presented at the PLEA 2017, Design to Thrive, Edinburgh.
- Farkas, K., Horvat, M. (2012). Building Integration of Solar Thermal and Photovoltaics - Barriers, Needs and Strategies (No. T. 41.A.1), IEA SHC Task 41 Solar energy and Architecture. IEA SHC.
- FOSTER inMED, 2015. Guidelines on building integration of photovoltaic in the Mediterranean area.
- Herzog, T., Krippner, R., Lang, W. (2004). *Facade Construction Manual*, DETAIL. ed. Birkhäuser, Germany.
- IEA - SHC, 2013. Designing photovoltaic systems for architectural integration. Criteria and guidelines for product and system developers.
- Jelle, B.P., Breivik, C., Røkenes, H.D. (2012). Building integrated photovoltaic products: A state-of-the-art review and future research opportunities. Elsevier.
- Lane, T. (2010). Embodied energy: the next big carbon challenge [on-line document]. URL <http://www.building.co.uk/embodied-energy-the-next-big-carbon-challenge/5000487.article> (accessed 9.16.16).
- Munari Probst, M.C., Roecker, C., Frontini, F., Scognamiglio, A., Farkas, K., Maturi, L., Zanetti, I. (2012). Solar Energy Systems in Architecture, Integration criteria and guidelines (No. T.41.A.2), IEA SHC Task 41 Solar energy and Architecture. SHC, Solar heating and cooling programme.
- Roberts, S., Guariento (2009). *Building Integrated Photovoltaics / A Handbook*. Birkhäuser.
- SFOE, (2014). *Energy Strategy 2050*.
- SUPSI, (2015). Centre Suisse de compétence BIPV [on-line document]. URL [www.bipv.ch](http://www.bipv.ch)
- Vieira, F.M., Moura, P.S., de Almeida, A.T., (2016). Energy storage system for self-consumption of photovoltaic energy in residential zero energy buildings. *Renew. Energy* 103 2017 308–320.
- Zhang, Y., Lundblad, A., Campana, P.E., Yan, J., (2015). Employing Battery Storage to Increase Photovoltaic Self-sufficiency in a Residential Building of Sweden. *Energy Procedia* 455–461.

# Optimizing WWR for conserving energy in office buildings for cooling dominant climates with and without daylight utilization

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**Abstract:** It is estimated that the building sector consumes up to 40% of global energy and is responsible for around 30% of global GHG emissions. The commercial sector has become the fastest growing energy demand sector globally. The construction of fully glazed commercial building facades responsible for high energy consumption has become a common architectural practice worldwide irrespective of the climate. Nonetheless, careful analysis of glazing configurations at early design stages can help control building energy consumption. Only few studies have analyzed the optimization of glazing system in the buildings for cooling dominant climates. This paper presents the methodology to optimize the Window to Wall Ratio (WWR) with and without daylight utilization to reduce energy consumption in office buildings for the climate of Lahore, Pakistan using a simulation tool COMFEN. An office building reference room with double glazed clear glass was developed and series of simulations were performed on each orientation. The impacts of the solar heat and daylight entering through the building façade with reference to different WWR and orientation were explored for the selection of optimum WWR. The optimum WWR was selected on the basis of least energy consumption and satisfaction of preset threshold criteria. When daylight is not utilized, the energy demand is minimized by the lowest possible WWR. With daylight utilization, energy demand is optimized by use of WWRs of 13% to 30% according to orientation. The optimum WWR with daylight utilization saved up to 12% more energy in comparison to optimum WWR without daylight utilization. However, the energy demand increases significantly with WWRs higher than the optimum WWR in both the cases. The methodology used in this study can be applied to any location around the world to find optimum WWR for any glazing type (such as tinted, reflective, low-e).

**Key words:** Optimum WWR, Building energy demand, Daylight utilization, Cooling dominant climate, Threshold criteria

## Introduction

Buildings not only provide the context of our lives but are also accountable for almost all of our energy use. Unfortunately, the current building stock is oriented towards high energy consumption (Hirst, 2013). It is estimated that the building sector consumes up to 40% of global energy and is responsible for around 30% of global GHG emissions (Lee et al., 2013; UNEP SBCI, 2009). The greatest portion of energy is used during the operational phase (use stage) of buildings to meet various energy needs such as heating, cooling, lighting, appliances etc (Singh, 2012; UNEP SBCI, 2009). The glazed building components play an important role in determining the operational energy requirement of buildings (Raheem et al., 2016). Roaf et al., (2005) considered excessive use of glass in the building envelope a major climatic design problem of today's buildings responsible for high energy demands and emissions. Historically, the building Cite de Refuge documented by Banham in 1984 was the first documented case of overheating with serious health issues for the occupants due to an entirely glazed façade (Butera, 2005).

Highly glazed commercial building facades have become a modern architectural trend worldwide irrespective of the climatic conditions (Butera, 2005; Bahaj et al., 2008). Moreover, the commercial sector has become the fastest growing energy demand sector globally (EIA, 2016). Lahore, the second largest city of Pakistan has semi arid hot climate. Like other modern cities of the world, it has also become a common practice to build

commercial buildings with extensive glazing in Lahore without any climatic considerations. These buildings consume more energy (mainly electricity) to maintain comfortable indoor environment (Tirmizi, 2010; Hameed et al., 2014; Saeed et al., 2013). A case study done for analyzing energy consumption patterns in typical highly glazed office building in Lahore concluded that a large amount of energy is being used for cooling and interior lighting accounting for 29% of the total energy for cooling and 53% for lighting (Saeed et al., 2013). Much of the commercial building stock in Pakistan has been constructed without considering energy efficiency measures. There is a need to employ energy conservation strategies in such buildings as energy consumption in commercial sector in Pakistan is increasing at the rate of 11.6% per year making it as one of the highest compared to other sectors of energy consumption (Hameed et al., 2014). Additionally, Pakistan a developing country of South Asia is highly energy deficient country and the energy situation in the country has turned into a crisis. Therefore, Government is also emphasizing on demand and supply management through the concepts of energy efficiency and conservation (PEECA, 2017).

Appropriate window design is one of the design approaches to reduce energy consumption in buildings. Heat loss/gain caused by thermal transmissions and also the effects of incident solar radiation should be considered to assess the energy performance of glazed building components (Moorjani and Asadi, 2014). According to studies, careful analysis of glazing configurations at design stages can help control building energy consumption (Ochoa et al., 2012; Poirazis et al., 2008).

Different studies have been conducted to analyze the impacts of glazing on energy consumption of buildings both in hot and cold climates. According to Lee et al., (2013), limited researches have been carried out on windows and their effects on building energy consumption for Asian regions and only few studies exist on the optimization of glazing in buildings (Jaber and Ajib, 2011; Arıcı and Karabay, 2010; Lee et al., 2013). The study of daylight integration to reduce artificial lighting energy consumption remains largely unexplored in context of Pakistan. Therefore, this paper presents the methodology to optimize the Window to Wall Ratio (WWR) with and without daylight utilization to reduce energy consumption/demand in office buildings for climates similar to Lahore, Pakistan using a simulation tool COMFEN. An office building typology is considered in this study. Since, within the building sector, office buildings are the largest consumer of energy due to their specific and homogenous energy requirements (e.g. air conditioning, artificial lighting, IT equipment, appliance) (Stegou-Sagia et al., 2007; Pérez-Lombard et al., 2008). Moreover, it is also advisable to start commercial building analysis for energy conservation with the office building typology (Pérez-Lombard et al., 2008).

## **Literature review**

### ***Window to Wall Ratio (WWR) and energy consumption***

Glazing area (WWR) is one of the important parameters of window system design both due to aesthetics and energy performance. The selection of glazing areas is part of initial design stages which is hard to change later (Ochoa et al., 2012; Poirazis et al., 2008). WWR has significant impact on total energy requirement of the building due to effects of solar radiations (visible light and heat) and increased heat transfer due to high conductivity of glazed area compared to walls (Lee et al., 2013; Su and Zhang, 2010). In general annual cooling and total energy requirement of the building increase with the increase in glazing area (Eskin and Türkmen, 2008). Ghisi and Tinker (2005) found that the window areas could



be larger on the façade which has smaller solar thermal loads (low solar radiation) to ensure low energy consumption. The summer energy needs increase with the increase in window areas due to intense solar radiation. However, increased window areas enhance winter performance with reduced heating loads. In terms of WWR, 50% WWR on north façade and 25% WWR on east, west and south facades were found the most efficient for saving energy in buildings in cooling dominant Asian climates (Lee et al., 2013). In another study, Al-Homoud (1997) found glazing area of 15% suitable for all the orientations to reduce annual energy consumption for office buildings in cooling dominant climates of U.S. and Saudi Arabia. A reduction in the glazing area affects many benefits associated with glazing such as aesthetics, views and daylight. However, optimizing WWR solely for visual comfort and aesthetics significantly increases the energy consumption pattern. Different researches have emphasized that optimization techniques should be adopted for selection of suitable glazing area to offer a balanced solution (Hee et al., 2015; Ochoa et al., 2012).

In summer, the window area is a source of increased heat gain which must be handled by cooling air conditioning system (Hassounah et al., 2010). The air conditioning system is a major consumer of total energy. The building sector consumes 65% of the total building energy for air conditioning in China (Yang et al., 2008) and 57%, 59% and 50% in Malaysia, Thailand and Saudi Arabia respectively (Saidur, 2009). Rashid et al. (2016) investigated the impact of window size on heat gain in commercial buildings in semi-arid climate of Lahore. It was seen that the heat gain increase with the increase in window size on all orientations and so is the cooling load. It is recommended by different studies that the key objective should be to avoid a high cooling demand to ensure low total energy consumption while specifying the glazed area in cooling dominant regions (Poirazis et al., 2008; Lee et al., 2013). Ahmed et al., (2013) found 10.5% of cooling energy savings by minimizing the window size in small office building in hot climate.

### ***Daylight and energy consumption***

Daylight utilization offset the energy consumption of the building by reducing artificial lighting load and also the cooling load associated with artificial lighting (Li et al., 2005; Mathew and Kini, 2016; Chen and Wei, 2013). Literature study revealed that cooling and lighting consume major part of total energy in office buildings. According to Bakker et al., (2017) artificial lighting consumed 20-45% of the total energy consumption in office buildings. A significant amount of energy could be saved by integrating daylight and electric light through good lighting control (Halliday and Halliday, 2008). Li et al., (2006) discovered that over 30% of electric lighting energy consumption could be saved by using daylight with dimming controls in cooling dominant office building in Hong Kong. Bodart and De Herde (2002) concluded that artificial lighting energy consumption could be reduced by 50-80% by properly utilizing daylight. Daylight utilization is considerably important for cooling dominated commercial buildings due to dual benefits of energy reduction in lighting and cooling load (Tian et al., 2010). Lam and Li (1999) found 11% and 13% reductions in peak cooling load and annual electricity consumption respectively with the proper use of daylight in generic 40 storey office building in Hong Kong. Window area is also found to be critical variable in determining daylighting entering into the building (Huang et al., 2014; Lee et al., 2013). However, a large window area does not necessarily mean significant increase in useful daylight. A 30% WWR was identified as the daylighting saturation point for south-facing facades in Montreal (Tzempelikos and Athienitis, 2007). According to another study,

beyond 25% (plus or minus 5%) glazing starts becoming a net energy loser and does not contribute more daylight (Wilson, 2010).

### **Simulation tool**

Numerous researches (Tsikaloudaki et al., 2012; Tzempelikos and Athienitis, 2007; Al-Homoud, 1997; Ko, Elnimeiri and Clark, 2008) have emphasized that the fenestration/glazed components of a building façade should be studied in early stages of design to understand their energy consumption for designing energy efficient buildings. The COMFEN (COMmercial FENestration) an early design energy modeling tool developed by LBNL (Lawrence Berkley National Laboratory) was used to achieve the objective of this study. COMFEN is a reliable tool for comprehensive analysis of building glazing system with respect to energy efficiency and comfort (Lee et al., 2009). It uses the powerful calculation engines such as EnergyPlus, WINDOW and RADIANCE (Selkowitz et al., 2014).

### **Simulation methodology**

This section describes the methodology used to find the optimum WWR for reducing energy demand in office building for cooling dominant climates. The impact of altering WWR was studied on the energy consumption of building with and without daylight utilization for each orientation (north, south, east, west). The results achieved were compared on the basis of the unit MJ/m<sup>2</sup>-yr known as the energy use intensity (EUI). This common reference was used to determine the optimum WWR. Without daylight utilization, the optimum size was identified on the basis of least energy consumption for each orientation. The present study also aims to identify optimum WWR with daylight utilization. A dynamic daylight performance metric DA (Daylight Autonomy) was used to implement daylighting in a building. DA is defined as a percentage of occupied time during the year when a certain user defined lux threshold is met by daylight alone. It uses illuminance at working plane as an indicator of sufficient daylight and use of occupancy hours as a time basis (Reinhart et al., 2006). DA is regarded as a comprehensive parameter since it considers the effects of orientation, climate and fenestration optical properties to describe the daylighting performance of the space (Tzempelikos and Athienitis, 2007). With daylight utilization, identification of optimum WWR for each orientation was based on the lowest energy consumption for the parameters at which the work plane illuminance threshold criteria of 500 lux was met by daylight alone for 50% of the occupancy time during the year. Annual energy consumption and daylight availability at the working plane were calculated.

### **Input data**

ASHRAE standards recommend to separating perimeter and interior zones of a building for energy modeling (ASHRAE, 2010). A reference room 4.0m wide and 3.6m high was established with perimeter zone depth of 4.57m (considered as thermal and daylight lighting zone depth as per ASHRAE standard 90.1 and International Energy Conservation Code (IECC). It was assumed that the reference office room forms part of a perimeter zone of an office building. The reference office room had single exterior façade wall and adiabatic interior walls, ceiling/roof, and floor. Glazing used was Double Glazed, clear glass (DGI). It was also assumed that there was no shading from additional shading devices or any surrounding buildings.

Input data required in this study for an office building/reference room including thermostat set points, Schedules (occupancy, lighting, equipment), outdoor air flow rate were set according to default values of COMFEN. The loads for each schedule were set according to ASHRAE standards. Work place density, miscellaneous equipment power and artificial Lighting Power Density (LPD) for an office building were specified as 9 m<sup>2</sup>/ person, 8.07 W/m<sup>2</sup> and 10.76 W/m<sup>2</sup> respectively. Fluorescent lighting was assumed. The illumination level of 500 lux was specified at the work plane height during office hours as recommended by ASHRAE standards and IESNA (Rea, 2000). Daylight controls were considered in this study to investigate the impacts of daylight utilization on building's energy consumption. Daylight control logic is embedded in the software COMFEN. Daylight controls in the form of photo sensors are used. A daylight sensor is positioned 2/3 of zone depth from the façade wall and positioned at desk height of 0.76 m above the floor (Mitchell et al., 2012). Continuous lighting controls were used in this study providing continuous dimming control based on daylight levels to maintain constant, undisturbed, fluorescent light levels during the office hours.

WWRs in the range of 10%, 20%, 30%, 40% and 80% were considered for this study. A WWR of 80% has been included in the pattern considering the current trends of maximizing glazing in building facades. The WWRs considered for simulation are shown in Figure 1. Window position has significant effect on lighting energy demand when there is a daylight control system. Window position in the centre of the façade was considered in this study due to being most advantageous when daylight controls are to be used (Bokel, 2007).

The outdoor climatic data used in this study including monthly average temperatures, horizontal solar radiations, horizontal illuminance was obtained using TMY2 data file. These weather files are data sets of hourly values of solar radiation and meteorological elements for a period of one year.

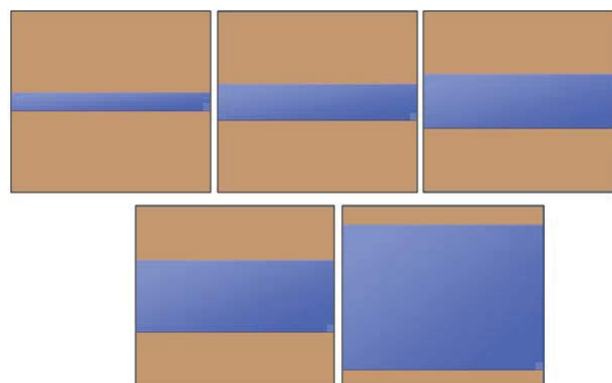


Figure 1. Different WWRs (10%, 20%, 30%, 40%, 80%) used for the simulation

## Results and Discussion

### *Optimum WWR without daylight utilization*

The results of the calculation for finding optimum WWR without daylight utilization are shown in Figures (2-5). Different WWRs (10%, 20%, 30%, 40% and 80%) were simulated with DGI to find annual energy consumption for each orientation.

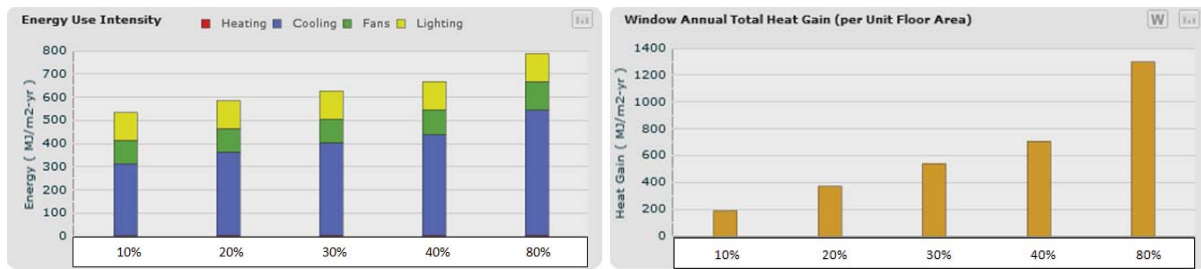


Figure 2. Comparison of energy consumption and heat gain of different WWRs for East orientation

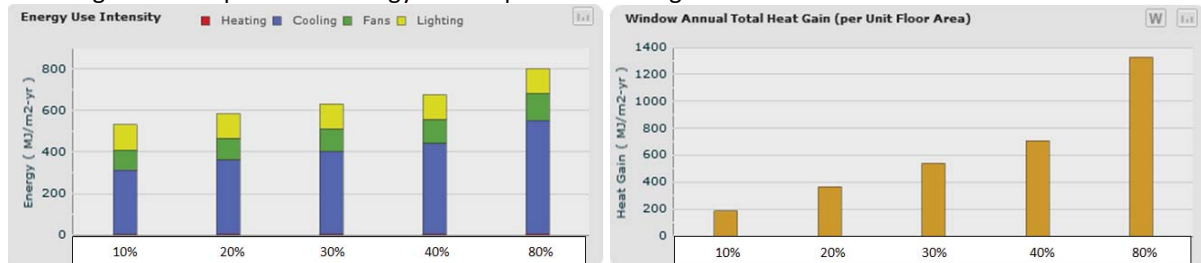


Figure 3. Comparison of energy consumption and heat gain of different WWRs for West orientation

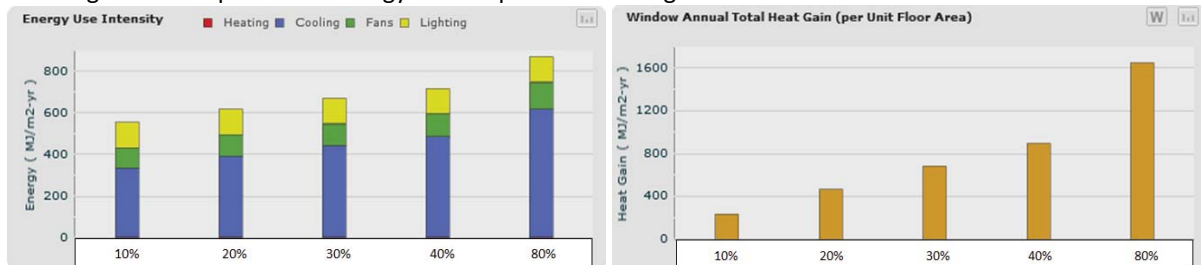


Figure 4. Comparison of energy consumption and heat gain of different WWRs for South orientation

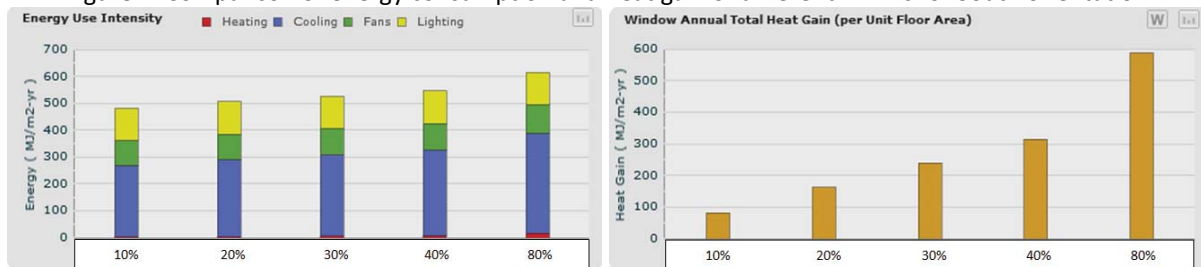


Figure 5. Comparison of energy consumption and heat gain of different WWRs for North orientation

It is evident from the results that WWR has significant impact on building energy consumption and building energy use increase with the increase in WWR. Results show that cooling loads are the most prominent and lighting loads are constant when daylight is not being utilized. These both greatly contributed to total energy consumption of the building. It can also be observed from the Figures (2-5) that heat gain increase with the increase in WWR on all the orientation and hence the cooling load and total energy consumption of the building. Therefore, reducing the penetration of solar radiations/heat through windows is essential for saving energy in cooling dominant climates. When daylight is not utilized, the energy demand is minimized by the lowest possible WWR. Minimum WWR of 10% was used in the study and identified as the optimum glazing size for north, south, east, west orientations for conserving energy in cooling dominant climates. Total energy consumption and heat gain at 10% WWR for all the orientations are presented in Table 1. The impact of window size on energy consumption of building was found to be maximum on a south orientation and minimum on a north orientation due to the variation in amount and penetration of solar radiations. As north orientation had the least impact on energy consumption compared to other orientations therefore, a higher WWR could be planned on

the north side for cooling dominant regions. E.g. WWR in the range of 30% to 40% could be planned on north orientation in comparison to 10% WWR on east, west and south orientations (Figure 6). This study also indicated that a WWR of 80% consumed 22% to 36% more energy depending upon orientation compared to optimum WWR.

Table 1. Total energy consumption and heat gain at 10% WWR for East, West, South and North orientation without daylight utilization

Orientation	WWR	Heating MJ/m <sup>2</sup> -yr	Cooling MJ/m <sup>2</sup> -yr	Fans MJ/m <sup>2</sup> -yr	Lighting MJ/m <sup>2</sup> -yr	Total energy consumption MJ/m <sup>2</sup> -yr	Window total heat gain MJ/m <sup>2</sup> -yr
East	10%	1.85	311.98	97.27	121.41	532.53	188
West	10%	1.93	310.72	97.61	121.41	531.68	187
South	10%	1.20	332.50	98.09	121.41	553.20	235
North	10%	3.12	264.12	94.21	121.41	482.86	82

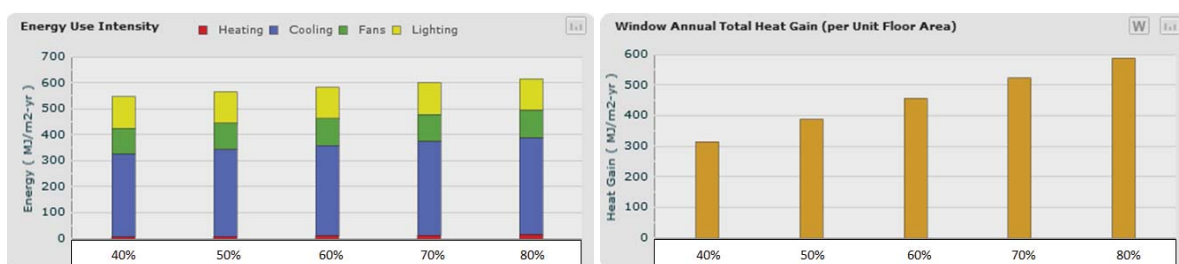


Figure 6. Comparison of energy consumption and heat gain of different WWRs for North orientation

### Optimum WWR with daylight utilization

It was found from the simulation results that daylight utilization reduced building energy demand significantly by reducing artificial lighting requirement and also the cooling load associated with artificial lighting. However, optimum glazing size selection with daylight utilization was based on the lowest energy consumption for the parameters which satisfied the preset threshold criteria. For east and west orientation, with DGI, the required illumination (500 lux) was provided at the working plane by daylight alone for 44% and 77% of the occupancy time with 20% and 30% WWR respectively. Further WWRs between 20% to 30% were simulated to investigate the optimum condition for energy demand reduction and find a WWR that provided the required daylighting. Energy consumption and daylight availability at different WWRs for these two orientations are presented in Figures (7, 8) and Tables (2, 3). A WWR of 23% was found optimum for east and west orientations that provided the required illumination at the working plane with daylight alone for 55% of the working time.

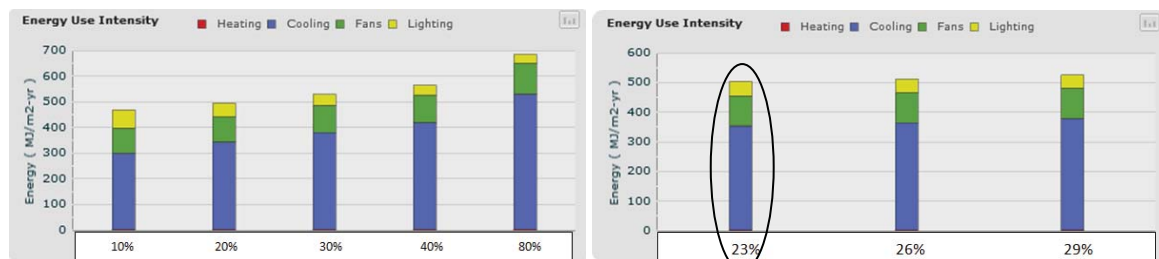


Figure 7. Comparison of energy consumption of different WWRs for East orientation with daylight utilization



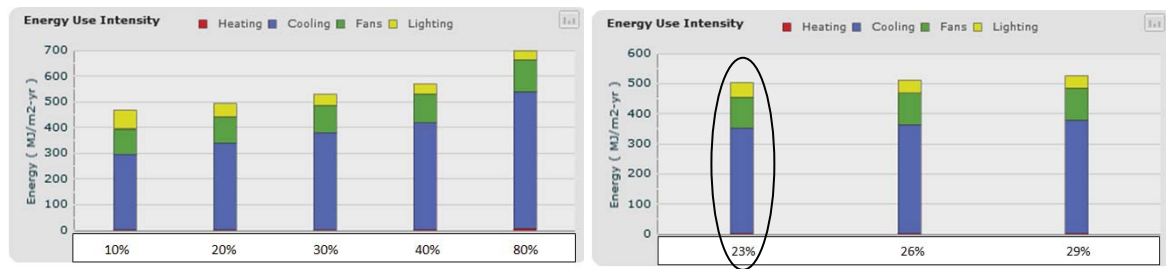


Figure 8. Comparison of energy consumption of different WWRs for West orientation with daylight utilization

Table 2. Annual average hourly daylight (lux) at different WWRs for East orientation

WWR	Annual average hourly daylight (lux) for five counted hours				
	9.00 AM	10.00 AM	11.00 AM	12.00 PM	1.00 PM
20%	3037	1594	944	629	454
23%	3806	1761	1068	712	514
30%	4666	2198	1391	927	668

Table 3. Annual average hourly daylight (lux) at different WWRs for West orientation

WWR	Annual average hourly daylight (lux) for five counted hours				
	1.00 PM	2.00 PM	3.00 PM	4.00 PM	5.00 PM
20%	479	699	1040	1683	3190
23%	542	790	1176	1858	3930
30%	705	1029	1532	2699	4790

After comparing all the WWRs for daylight availability for north and south orientation, a WWR of 30% was identified optimum for north orientation. It provided the adequate daylight illumination levels throughout the working time. It was found that a WWR of 20% could not provide the required threshold of 500 lux for any hour during the working time for north orientation. For south orientation, the required illumination at the working plane was achieved by daylight alone (through DGI) for 33% and 88% of the occupancy time with 10% and 20% WWR respectively. WWRs between 10% to 20% were then simulated to find the optimum condition for energy demand reduction in order to find a WWR that provided the required daylighting. A WWR of 13% was identified as optimum glazing size for south orientation satisfying the pre set criteria for 66% of the working time. Energy consumption and daylight availability at different WWR for these two orientations are presented in Figures (9, 10) and Tables (4,5).

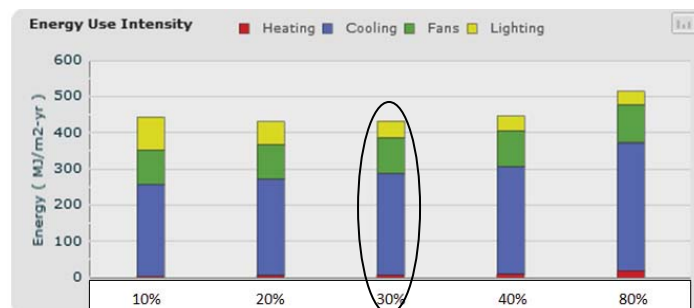


Figure 9. Comparison of energy consumption of different WWRs for North orientation with daylight utilization

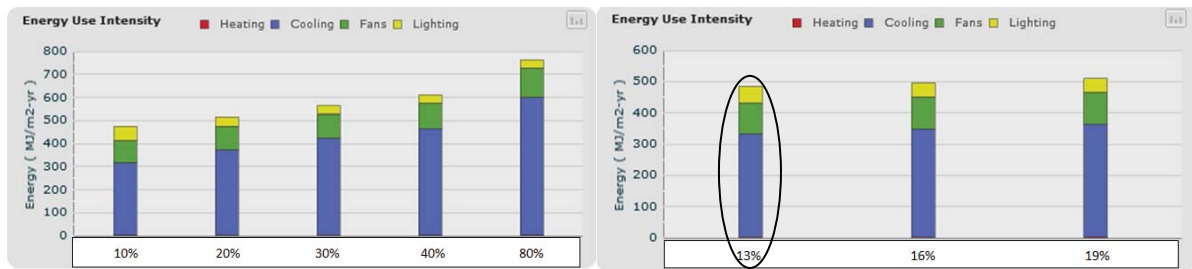


Figure 10. Comparison of energy consumption of different WWRs for south orientation with daylight utilization

Table 4. Annual average hourly daylight (lux) at different WWRs for North orientation

WWR	Annual average hourly daylight (lux) for five counted hours				
	10.00 AM	11.00 AM	12.00 PM	1.00 PM	2.00 PM
20%	372	371	364	361	368
30%	545	544	535	532	540

Table 5. Annual average hourly daylight (lux) at different WWRs for South orientation

WWR	Annual average hourly daylight (lux) for five counted hours				
	10.00 AM	11.00 AM	12.00 PM	1.00 PM	2.00 PM
10%	388	486	541	558	535
13%	505	632	704	727	697
20%	773	969	1080	1114	1068

The optimum glazing size is different for different orientations with daylight utilization due to different solar conditions. In terms of WWR, 30% WWR on north orientation, 23% WWR on east, west orientation and 13% WWR on south orientation were found the most effective for energy conservation in cooling dominant regions. Total annual energy consumption and artificial lighting reduction due to daylight utilization at optimum WWR are presented in Table 6. Relatively higher WWR could be planned on north orientation due to low solar radiations. Although direct sunlight is not available on north orientation in northern hemisphere however, higher WWRs (30% to 80%) on north orientation were found to provide sufficient daylight levels throughout the occupancy hours without overheating (Figure 11). South orientation potentially receives useful daylight (acceptable illumination levels) throughout the working time up to 40% WWR. However, a WWR of 13% was found optimum for south orientation allowing natural light to bathe the space for most of the working time without overheating. The south orientation was found better than east and west orientations for daylight levels. High illumination levels (causing glare or visual discomfort) were observed during morning and evening hours for east and west orientation due to the low solar altitudes. It was also found that a WWR of 80% consumed 16% to 36% more energy depending upon orientation compared to optimum WWRs in this case.

Table 6. Total annual energy consumption and artificial lighting reductions at optimum WWR for East, West, North and South orientation with daylight utilization

Orientation	WWR	Heating MJ/m <sup>2</sup> -yr	Cooling MJ/m <sup>2</sup> -yr	Fans MJ/m <sup>2</sup> -yr	Lighting MJ/m <sup>2</sup> -yr	Total energy consumption MJ/m <sup>2</sup> -yr	Reductions in artificial lighting requirement %
East	23%	2.11	351.31	100.86	50.03	504.32	59%
West	23%	2.46	349.57	102.82	48.20	503.04	60%
North	30%	6.22	281.47	97.54	47.30	432.54	61%
South	13%	1.35	331.37	99.24	54.07	486.06	55%

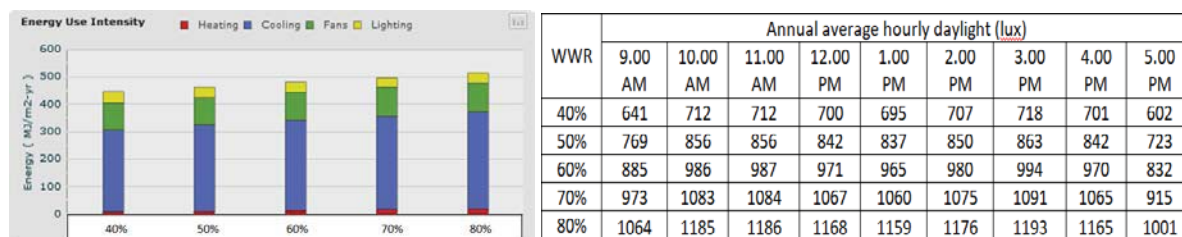


Figure 11. Energy consumption and daylight availability at different WWRs for North orientation

Annual energy consumption with optimum glazing size without and with daylight utilization was compared to find the most suitable choice for conserving energy. It was found that optimum WWR with daylight utilization saved around 5.2%, 5.4%, 10.4% and 12% more energy for east, west, north and south orientations respectively in comparison to optimum WWR without daylight utilization. Moreover, the optimum WWR for all orientations with daylight utilization was higher than the optimum glazing size without daylight utilization.

## Conclusion

This study highlighted that significant energy savings in glazed commercial buildings in cooling dominant climates are possible by utilizing optimum WWRs. Without daylight utilization, the study identified a WWR of 10% as the optimum size for saving energy for north, south, east, west orientations. 22% to 36% of the energy could be saved by reduction of WWR to 10% for all orientations from the currently conventional 80% WWR. With daylight utilization, energy demand is reduced by 26% to 28% by use of 23% WWR for east and west, 36% reductions are available from 13%WWR on south and 16% from 30%WWR on north facades compared to 80% WWR. These optimum WWRs provide daylighting levels above 500 lux at desk level for more than 50% of the working time. The results showed that the heat gained through the window is responsible for the excessive energy demand in Lahore (a cooling dominant region). Therefore, the control of penetration of solar radiations through windows is essential for saving energy. Daylight utilization reduced the building energy demand by reducing artificial lighting energy requirement and the cooling load associated with artificial lighting. However, the decrease in cooling load due to reduction in electric lighting was smaller than the reduction in artificial lighting load further emphasizing on the role of solar penetration in cooling energy consumption of building.

In order to reduce the energy demands, a choice, therefore, needs to be made between taking advantage of natural daylighting through appropriate WWR, thus minimizing the use of artificial lighting and minimization of WWR to 10% to reduce heat gains through windows. However, optimum WWR with daylight utilization offers more balanced solution than the optimum WWR without daylight utilization for all the orientations due to being more energy efficient as well as provides more visual connection to outside. Shading devices were not considered as analysis of daylight utilization was one of the main objectives of this research.

## References

- Ahmed, K., Badshah, S., Rafique, A.F. and Khan, M.A. (2013). Windows optimization for office buildings in Islamabad Pakistan. *International Journal of Scientific & Engineering Research*, 4(4), pp. 1658–1664.
- Al-Homoud, M. (1997). Optimum thermal design of office buildings. *International Journal of Energy Research*, 21(10), pp.941-957.
- Arıcı, M. and Karabay, H. (2010). Determination of optimum thickness of double-glazed windows for the climatic regions of turkey. *Energy and Buildings*, 42(10), pp. 1773–1778.

- ASHRAE (2010) *ASHRAE standard 90.1-2010. Energy Standard for Buildings except Low-Rise Residential Buildings*. American Society of Heating, Refrigerating and Air-Conditioning Engineers.
- Bakker, C., Aries, M., Kort, H. and Rosemann, A. (2017). Occupancy-based lighting control in open-plan office spaces: A state-of-the-art review. *Building and Environment*, 112, pp.308-321.
- Bahaj, A.S., James, P.A.B. and Jentsch, M.F. (2008). Potential of emerging glazing technologies for highly glazed buildings in hot arid climates. *Energy and Buildings*, 40(5), pp. 720–731.
- Bodart, M. and De Herde, A. (2002). Global energy savings in offices buildings by the use of daylighting. *Energy and Buildings*, 34(5), pp.421-429.
- Bokel, R. (2007). The effect of window position and window size on the energy demand for heating, cooling and electric lighting. In: *10th International IBPSA Conference; International Building Performance Simulation Association*. Beijing, China.
- Butera, F. (2005). Glass architecture: is it sustainable? In: *International Conference of Passive and Low Energy Cooling for the Built Environment*. Santorini, Greece, May 2005.
- Chen, H. and Wei, P. (2013). Utilization of natural daylight in office buildings. *International Journal of Smart Grid and Clean Energy*, 2(2), pp. 301–306.
- EIA. (2016). *International energy outlook 2016-Buildings sector energy consumption*. [Online] Available at: <https://www.eia.gov/outlooks/ieo/buildings.cfm> (Accessed: 4 February 2017).
- Eskin, N. and Türkmen, H. (2008). Analysis of annual heating and cooling energy requirements for office buildings in different climates in Turkey. *Energy and Buildings*, 40(5), pp.763-773.
- Ghisi, E. and Tinker, J.A. (2005). An ideal window area concept for energy efficient integration of daylight and artificial light in buildings. *Building and Environment*, 40(1), pp. 51–61.
- Halliday, Y. and Halliday, S. (2008). *Sustainable construction*. Oxford, England: Elsevier Science and Technology.
- Hameed, R., Nadeem, o., Altaf, S. and Ameen, F. (2014). Improving the energy efficiency of existing commercial buildings in Lahore through retrofitting technique. *Journal of Faculty of Engineering & Technology*, 21(2), pp. 95–104.
- Hassounah, K., Alshboul, A. and Al-Salaymeh, A. (2010). Influence of windows on the energy balance of apartment buildings in Amman. *Energy Conversion and Management*, 51(8), pp.1583-1591.
- Hee, W.J., Alghoul, M.A., Bakhtyar, B., Elayeb, O., Shameri, M.A., Alrubaih, M.S. and Sopian, K. (2015). The role of window glazing on daylighting and energy saving in buildings. *Renewable and Sustainable Energy Reviews*, 42, pp. 323–343.
- Hirst, N. (2013). Buildings and Climate Change. In: R. Yao, ed., *Design and Management of Sustainable Built Environments*, Springer London.
- Huang, Y., Niu, J. and Chung, T. (2014). Comprehensive analysis on thermal and daylighting performance of glazing and shading designs on office building envelope in cooling-dominant climates. *Applied Energy*, 134, pp. 215–228.
- Jaber, S. and Ajib, S. (2011). Thermal and economic windows design for different climate zones. *Energy and Buildings*, 43(11), pp. 3208–3215.
- Ko, D., Elnimeiri, M. and Clark, R. (2008). Fenestration guidelines for improving energy conservation in an the office building with a daylight control system. In: *Proceedings of the World Sustainable Building Conference*, Melbourne, Australia, 21-25 Sep 2008. CSIRO- Commonwealth Scientific and Industrial Research Organization
- Lam, J.C. and Li, D.H.W. (1999). An analysis of daylighting and solar heat for cooling-dominated office buildings. *Solar Energy*, 65(4), pp. 251–262.
- Lee, J., Jung, H., Park, J., Lee, J. and Yoon, Y. (2013). Optimization of building window system in Asian regions by analyzing solar heat gain and daylighting elements. *Renewable Energy*, 50, pp.522-531.
- Lee, E., Selkowitz, S., DiBartolomeo, D., Klems, J., Clear, R., Konis, K., Hitchcock, R., Yazdanian, M., Mitchell, R. and Konstantoglou, M. (2009) *High Performance Building Façade Solutions*. California Energy Commission, PIER. Project number CEC-500-06-041. Available at: <https://facades.lbl.gov/sites/all/files/lbnl-4583e.pdf> [Accessed 25 Mar. 2017].
- Li, D., Lam, T. and Wong, S. (2006). Lighting and energy performance for an office using high frequency dimming controls. *Energy Conversion and Management*, 47(9-10), pp.1133-1145.
- Li, D.H.W., Lam, J.C. and Wong, S.L. (2005). Daylighting and its effects on peak load determination. *Energy*, 30(10), pp. 1817–1831.
- Mathew, M. and Kini, S. (2016). Daylight Analysis of a Typical Low Rise Office Building for Different Climate Zones of India. In: *International IEEE Conference on Energy Efficient Technologies for Sustainability*, Nagercoil, India, 7-8 April 2016. IEEE

Moorjani, V. and Asadi, S. (2014). Assessing the Effects of Glazing Type on Optimum Dimension of Windows in Office Buildings. In: *50th ASC Annual International Conference Proceedings*, Associated Schools of Construction.

Mitchell, R., Yazdani, M., Zelany, K. and Curcija, C. (2012) *COMFEN 4.1: Program Description*. A PC Program for Calculating the Heating and Cooling Energy Use of Windows in Commercial Buildings. Available at: <https://windows.lbl.gov/software/comfen/4.1/COMFEN4.1-UserManual.pdf> [Accessed 26 Mar. 2017].

Ochoa, C.E., Aries, M.B.C., van Loenen, E.J. and Hensen, J.L.M. (2012). Considerations on design optimization criteria for windows providing low energy consumption and high visual comfort. *Applied Energy*, 95, pp. 238–245.

PEECA. (2017). *PEECA – Punjab Energy Efficiency & Conservation Agency*. [online] Available at: <http://peececa.gov.pk/> [Accessed 8 Sep. 2017].

Pérez-Lombard, L., Ortiz, J. and Pout, C. (2008). A review on buildings energy consumption information. *Energy and Buildings*, 40(3), pp. 394–398.

Poirazis, H., Blomsterberg, Å. and Wall, M. (2008). Energy simulations for glazed office buildings in Sweden. *Energy and Buildings*, 40(7), pp. 1161–1170.

Raheem, A., Issa, R. and Olbina, S., (2016). Environmental performance and economic analysis of different Glazing–Sunshade systems using simulation tools. *Journal of Computing in Civil Engineering*, 30(5), p.C5016001.

Rashid, M., Malik, A.M. and Ahmed, T. (2016). Effect of window wall ratio (WWR) on heat gain in commercial buildings in the climate of Lahore. *International Journal of Research in Chemical, Metallurgical and Civil Engineering*, 3(1), pp. 122–125.

Rea, M. (2000). *The IESNA lighting handbook*. New York, NY: Illuminating Engineering Society of North America.

Reinhart, C., Mardaljevic, J. and Rogers, Z. (2006). Dynamic Daylight Performance Metrics for Sustainable Building Design. *LEUKOS*, 3(1), pp.7-13.

Roaf, S., Crichton, D. and Nicol, F. (2005). *Adapting buildings and cities for climate change*. Amsterdam: Architectural Press.

Saeed, I., Khan, A., Arif, S. and Mushtaq, M. (2013). Electricity consumption for energy conservation in office buildings in lahore-pakistan. *Pakistan Journal of Science*, 65(2), pp. 243–246.

Saidur, R. (2009). Energy consumption, energy savings, and emission analysis in Malaysian office buildings. *Energy Policy*, 37, pp.4104-4113.

Selkowitz, S., Hitchcock, R., Mitchell, R., McClintock, M. and Settlemyre, K. (2014) *COMFEN – Early Design Tool for Commercial Facades and Fenestration Systems*. Available at: <https://eetd.lbl.gov/sites/all/files/comfen-software-tool.pdf>.

Singh, P. (2012). Buildings and Climate change. *Journal of Energy, Environment & Carbon Credits*, pp.61-67.

Stegou-Sagia, A., Antonopoulos, K., Angelopoulou, C. and Kotsiovelos, G. (2007). The impact of glazing on energy consumption and comfort. *Energy Conversion and Management*, 48(11), pp. 2844–2852.

Su, X. and Zhang, X. (2010). Environmental performance optimization of window–wall ratio for different window type in hot summer and cold winter zone in china based on life cycle assessment. *Energy and Buildings*, 42(2), pp.198-202.

Tian, C., Chen, T., Yang, H. and Chung, T. (2010). A generalized window energy rating system for typical office buildings. *Solar Energy*, 84(7), pp. 1232–1243.

Tirmizi, A. (2010). Sustainable building design strategies for Pakistan. In: *Central Europe towards Sustainable Building conference*. Prague. Available at: [http://cesb.cz/cesb10/papers/7\\_policy/103.pdf](http://cesb.cz/cesb10/papers/7_policy/103.pdf) (Accessed: 25 November 2016).

Tsikaloudaki, K., Laskos, K., Theodosiou, T. and Bikas, D. (2012). Assessing cooling energy performance of windows for office buildings in the Mediterranean zone. *Energy and Buildings*, 49, pp. 192–199.

Tzempelikos, A. and Athienitis, A.K. (2007). The impact of shading design and control on building cooling and lighting demand. *Solar Energy*, 81(3), pp. 369–382.

UNEP SBCI, (2009) *Buildings and Climate Change*. (Summary for Decision makers). Available at: <http://www.unep.org/SBCI/pdfs/SBCI-BCCSummary.pdf> (Accessed: 25 November 2016).

Wilson, A. (2010). *Rethinking the All-Glass Building*. [ONLINE] Available at: <https://www.buildinggreen.com/feature/rethinking-all-glass-building> [Accessed 13 Jun. 2017].

Yang, L., Lam, J.C. and Tsang, C.L. (2008). Energy performance of building envelopes in different climate zones in china. *Applied Energy*, 85(9), pp. 800–817.



# Classification and evaluation of Double Skin Façade Technologies in office Buildings in Hot Climates to Improve Thermal Comfort of Multiple-Skin Facades

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**Abstract:** The research aimed to Evaluating Double Skin Façade Technologies and their applications on Architectural Design FOR HEATING, COOLING AND VENTILATION to Improve Buildings Energy Performance and Enhancing Thermal Comfort using a simulation tool to test efficiency.

The concept of the DSF depends on the Stack Effect, which is created between two glass screens to remove the heat from the building in hot seasons or by using the greenhouse effect to warm up in cold seasons, Ventilated double skin façade (V.DSF) type, especially which depends on "Mixed-Mode" ventilation of both: HVAC system & Hybrid System ventilation strategy is considers the most Suitable, Economic application of (DSF) types in "Hot-arid" climatic zones such as Egypt.

Double wall technique, with variables of air gap, construction material, opening dimensions, and opening position, was investigated within local summer conditions using Energy Plus as a (CFD) simulation engine to study the system efficiency on flow rate and thermal comfort using Double Skin Façade Technologies with all orientations of solar exposure (east, south, and west orientations).

The analysis of gathered data conclude that (DSF) can give great benefit to indoor environment thermal comfort, air quality, daylight, noise protection compared to single skin glass facades, if involves a series of detailed performance analyses.

The research has shown that double façade configuration has possibility of providing acceptable internal thermal comfort through "Mixed-Mode" ventilation strategy in hot climate, this is important in determining the possibility of DSF in incorporating "Mixed-Mode" ventilation reducing energy usage in heating and cooling demands and is proven By applying a simulation using " Design-Builder " software of "Energy plus "simulation engine on a case-study of a model of Office building with two façade alternative Basecase.

**Keywords:** Double Skin Façade, CFD, natural ventilation, Heating & Cooling load.

## Introduction

The double-skin façade is an architectural phenomenon driven by the aesthetic desire of fully glazed curtain walls and as an effective way to control light, heat, cold air and noise through the building envelope and also to contribute on reducing energy consumption.

Despite in the last 10-20 years many authors have faced the issue of modelling DSFs, many houses utilized box-type windows to increase thermal insulation (Oesterle, 2000) in central Europe, while in Egypt annual electricity demand is increasing by 6-7%, this is attributed to the increase in annual energy consumption in most building used for, cooling, heating, ventilation, lighting, and in the built environment.

Ventilated double skin façade (V.DSF) type, especially which depends on "Mixed-Mode" ventilation of both: HVAC system & Hybrid System, ventilation strategy is considered the most Suitable, Economic application of (DSF) types in "Hot-arid" climatic zones in Egypt.

The proper design of the hybrid ventilation system must be based on the detailed understanding of airflows within enclosed spaces, at the design stage, CFD modelling techniques can be utilized to investigate the possible ventilation flow rates, temperature distribution and thermal stratification within the ventilated space.

## Literature Review

Different studies have been done on buildings with double skin which are going to be reviewed as following, a considerable amount of studies have been done about SSF and DSF. Most part of these studies was in European countries. Gratia and De Herde (2004, 2007a, b, c, d) simulated an office building with thermal analysis software (TAS) and evaluated performance and influence of DSF.

They explored natural ventilation in double skin façade and its influence on temperature of DSF surfaces (Gratia et al, 2004), they showed that DSF is not so energy efficient as it seems in first but it could have other advantages (Gratia and De Herde, 2007a) ,natural ventilation is a critical issue for DSF, Orientation of DSF had significant importance on greenhouse phenomenon (Gratia et al, 2007b) ,they also presented that cross natural ventilation can lead to indoor thermal comfort in summer conditions in multi storey office buildings (Gratia et al ,2007c) , Solar shading could decrease cooling demand, according to (Gratia et al ,2007d), light coloured blinds in middle of cavity could save more cooling energy in comparison to other modes.

In Hong Kong, energy efficiency of an office building was investigated by Chan et al. (2009), their investigation showed that a double skin façade could be able save 26% cooling energy of office building as compared with single skin façade (Chan et al,2009).

There are some studies examine about DSF in hot and humid climate (Wong et al, 2008) have configured a new type of DSF, they started their research from simple one storey module and extended it to 18-storey office building, and they showed that DSF is really possible to be applied for natural ventilation in tropical climate.

On the other hand, lots of studies have been done on building form and its relation with solar energy like: Ling et al studied the effect of geometrical shape and building orientation in minimizing usage of solar insulator in high buildings in sticky air (Ling et al, 2007).

In another study, the research had simulated of the combined shaft-corridor DSF was carried out seven story stack high to investigate the thermal behaviour of this new design facade and evaluate the processes involved in thermal comfort, Fluent was used to simulate turbulent airflow(Azarbayjani, 2011), according to the mentioned researches, in hot climates except from a few cases showing weaknesses, advantages of these systems are more pronounced, motivating people to employ shading DSF systems associated with natural ventilation with high inclination angle against excessive solar radiation (Aokhamis et al , 2015) .

## Double-Skin Façade Concept

The Double-Skin Façade Concept can be defined as a combination of a traditional single-skin façade which is doubled or triple on the outside by a second layer, essentially an additional glazed façade. The layers of Double Skin Façade system can be arranged as:

Table 1. Description of Double Skin Façade (DSF).

Interior glazing	Insulating double (common) glazing unit (clear, low-E coating, solar control glazing, etc., can be used). Almost always this layer is not completely glazed.
The interior window	Can be opened by the user. This may allow natural ventilation of the offices.
The air cavity between the two skins	It can be totally natural, fan supported or mechanically ventilated. The width of the cavity can vary as a function of the applied concept between (20 cm) to more than (200 cm.), this width influence the way that the façade is maintained.
Exterior Glazing	Usually it is a hardened single glazing. This exterior façade can be fully glazed.
Vents (openings)	Sometimes in external or internal skin to allow natural ventilation of air cavity.

## Double Skin Façade (DSF) Configuration

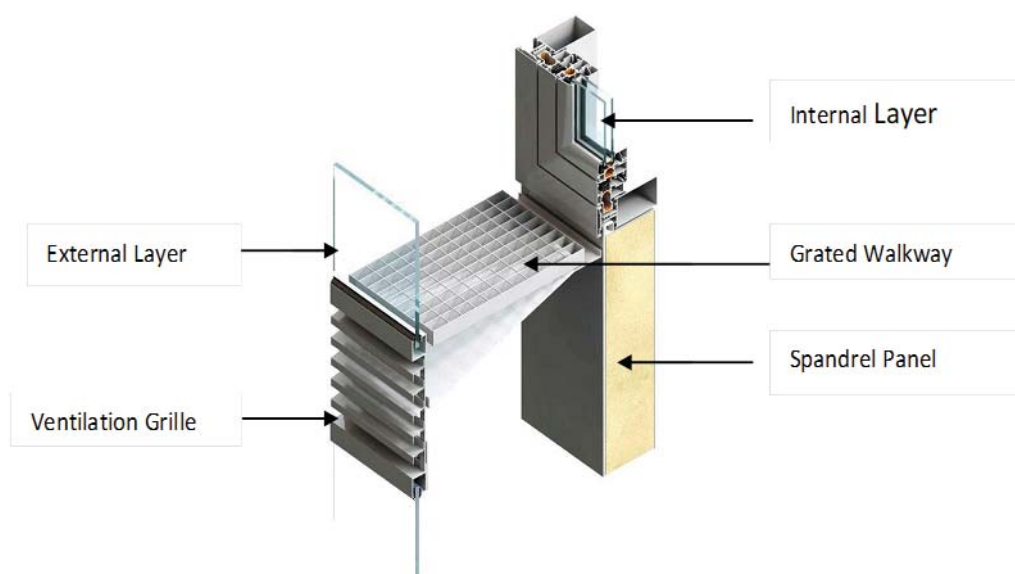


Figure 1. Typical Double-Skin Façade Configuration .

***There are four main categories of configuration of Double-Skin Façades, as mentioned below***

Box Façade ,Corridor Façade ,Shaft-Box Façade and Multi-Storey Façade .

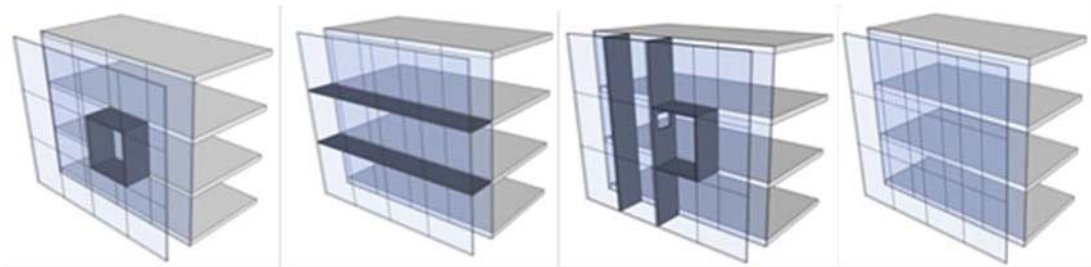


Figure 2. Box Façade , Corridor Façade , Shaft-Box Façade & Multi-Storey Façade (Aaron Regazzoli).

## Classification of Ventilated Double Skin Façades

***The Three main criteria for classifying Ventilated Double skin façade***

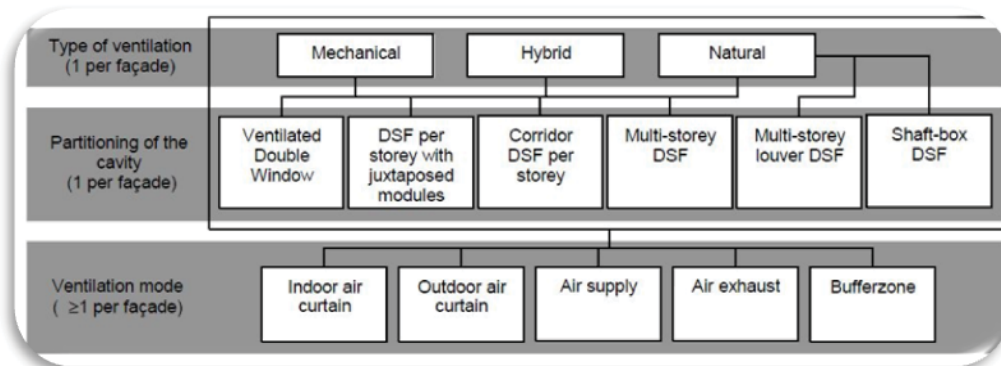


Figure 3. Classification of double skin glass facade systems (T. Boake).

Hybrid ventilation is designed to maintain acceptable indoor air quality that lies within comfort zone, also it can provide a comfortable internal environment using both natural ventilation and mechanical systems, but using different features of these systems at different times of the day or season of the year.

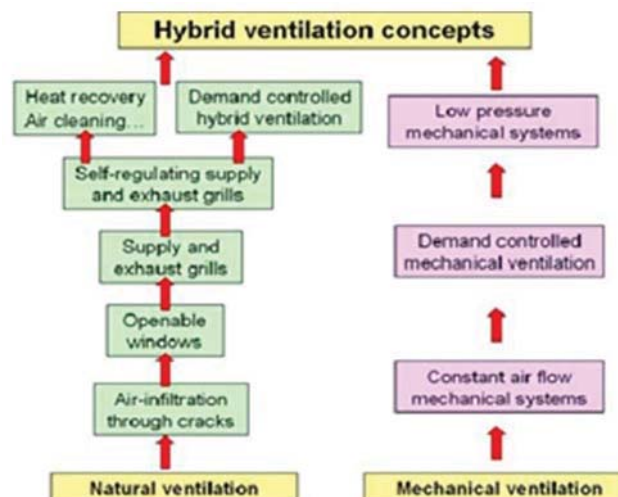


Figure 4. Hybrid Ventilation System Diagram (Olesen ,B.W).

Table 2. Air Cavity & Shading System Comparative Analysis among Design Parameters of (V.DSF) System in Office buildings.

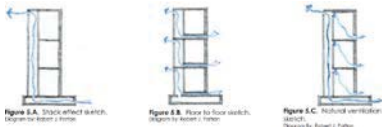
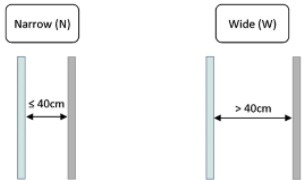
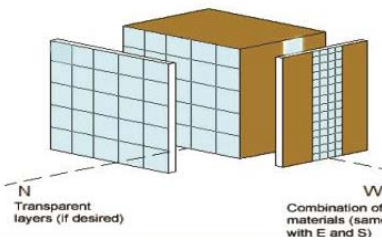
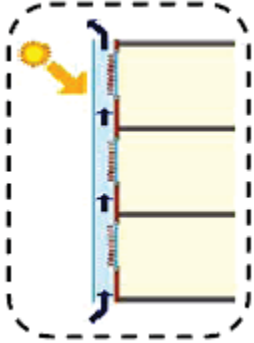
Design Parameters	Air Cavity	
Parameter Categories	Cavity Shape	Cavity width
Parameter Details	Corridor/ Multi story/ Shaft box	Small / Medium/ Large
Influence & Characteristics of parameters	<p>Corridor and Shaft-box types: are flexible for High and Mid-rise building which horizontal partitioning at each floor slab level for the following reasons:</p> <p>Support the fixation of whole façade system.</p> <p>Allowing easy movement of air within each floor for high rise building.</p> <p>Protect the other floors in case of fire emergency in the other floor and reduce fire spared.</p> <p>Multi-storey types: are suitable for Low-rise building.</p>	<p>Ventilation rate has direct impact on ventilation and façade efficiency.</p> <p>Ventilation rate through air cavity changing contrary with respect to cavity width: the thinner cavity width the higher and better rate of air ventilation.</p> <p>(U-value) of air cavity is almost constant after (25 cm s.) width; hence it is flexible as long as it facilitates ventilation of trapped air and climatic conditions of site, and season.</p>
Conceptual Sketches	 <p>Figure 8.A. Single-effect switch. (Narrow cavity &lt; 40cm)</p> <p>Figure 8.B. Place-to-face switch. (Narrow cavity &lt; 40cm)</p> <p>Figure 8.C. Hybrid ventilation switch. (Narrow cavity &lt; 40cm)</p>	 <p>Narrow (N) ≤ 40cm</p> <p>Wide (W) &gt; 40cm</p>
Design Parameters	Shading System	
Parameter Categories	Glazing & Materials Physical properties	Glazing Openings
Influence & Characteristics of parameters	<p>U Value : The Total (U-values) of façade materials and glazing system should be reduced to the minimum for reaching to maximum benefit.</p>	<p>It is better for (DSF) height to be higher than building height (with about 5.0 meters)</p>



Table 3. Façade Orientation Comparative Analysis among Design Parameters of (V.DSF) System in Office buildings .

Design Parameters	Façade Orientation	
Parameter Categories	Sun Exposure	Wind direction
Parameter Details	North /South East/West	Wind ward/ leeward/ Parallel ward
Influence & Characteristics of parameters	<p>Generally, Heat Gain of (DSF) is reduced by decreasing the time of (DSF) sun direct exposure, so:</p> <p>Northern façade orientation is the lowest exposed façade to the sun, then the lower Solar Heat Gain facade of the building.</p> <p>North east, and North west orientations, are respectively the lower facades in heat gain of after northern facades.</p>	<p>Cross day/night ventilation by extraction or replacement of air through the cavity of (V.DSF) and building inner spaces, depends mainly on the wind direction with respect to façade orientation and the Strategy of building ventilation if by : Day-time or night-time ventilation strategies.</p> <p>The impact of Wind direction (based on façade orientation) with respect to (DSF) position is not effective if (DSF) system was not opened from above, bottom of the system, or even outer skin opening.</p>
Conceptual Sketches	 <p>A 3D perspective sketch of a building facade. It shows a grid of transparent layers on the left, labeled 'N Transparent layers (if desired)'. To the right is a solid brown section labeled 'W Combination of materials (same with E and S)'. The sketch is oriented with North (N) and West (W) directions indicated.</p>	 <p>A 2D schematic diagram of a vertical double-skin facade system. It shows a cross-section with a sun icon on the left. Arrows indicate air flow: 'Exhaust' at the top and 'Supply' at the bottom. The system is enclosed in a dashed rectangular box.</p>

## METHODOLOGY

Simulation will be done by the aid of "Design Builder" software tool which mainly dependent on (Energy Plus), For proper evaluation of sustainability of "Base-Case"& (V.DSF), thermal comfort and energy consumption of its spaces could be considered as the main

criteria. First, thermal comfort indices and simulation processes are described. Then simulation results are presented and discussed.

For 'Base -Case' Model (Curtain wall system) : This model depends on Full (HVAC) system by using of (Chillers of Central air-condition units) for artificial mechanical ventilation supply.

Double wall technique results (0.5 m cavity corridor in front of the offices)

Double wall technique results (Over than 100 cm) - Large Type cavity corridor in front of the offices)

### Weather data file

The weather data file used for this study is EGY\_AL QAHIRAH\_CAIRO INTL AIR PORT \_ETMY.stat.

Table 4. Details of Weather Data File used for simulation.

Weather Data File	EGY_AL QAHIRAH_CAIRO INTL AIRPORT_ ETMY. epw
Type	Hourly weather data
Location	Cairo, Egypt, Africa WMO Region 1
Source	Egyptian Typical Meteorological Year (ETMY)

### Study Models design & Office Building model description

#### *General office building design data*

Table 5. Office Building Architectural Data.

Building type	Office building
Room 1	12 person/100 m2
Building floors numbers	Ground floor + (3) typical floors
Typical office floor height	4.0 m (slab to slab), 3.70 m ~ 3.0 m (clear height)
Building total height	(4.0 m * 4 floors) + 2.0 m parapet of façade= 18.0m
Ground floor area	20.0 m *10.0 m = 225 m2

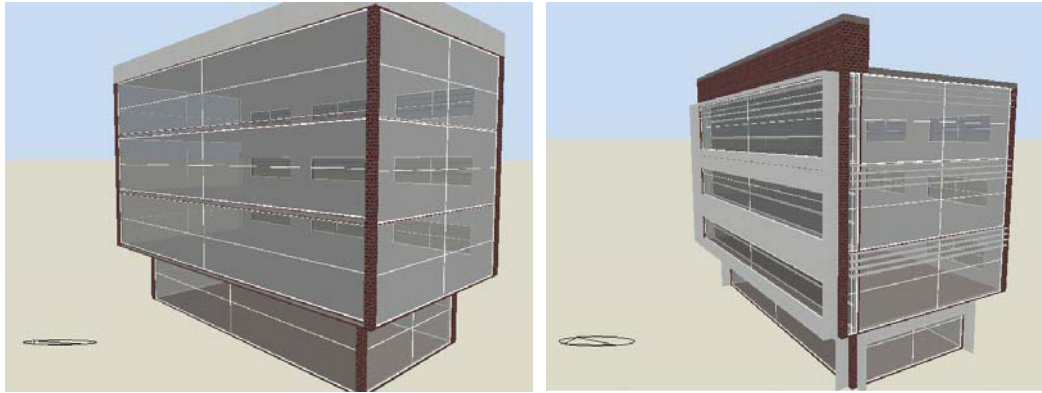


Figure 5. Base-Case & Ventilated Double Skin Façade (V.DSF) Model , Design Builder Screen shoot..

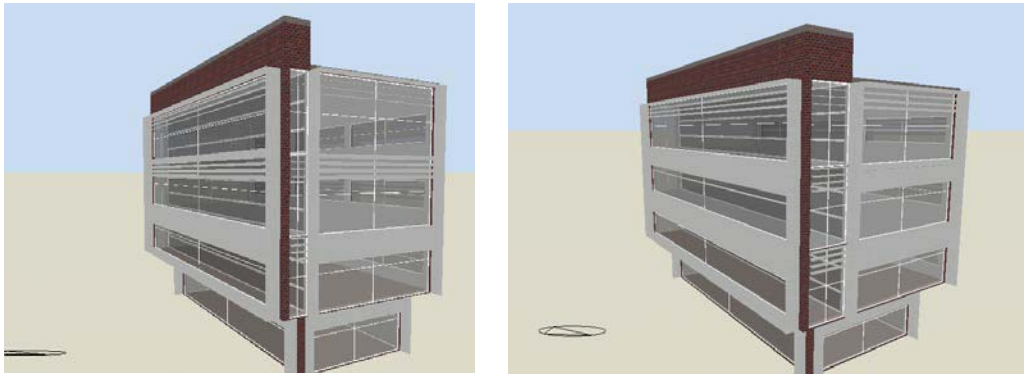


Figure 6. Ventilated Double Skin Façade (V.DSF) Models, Design Builder Screen shoot..

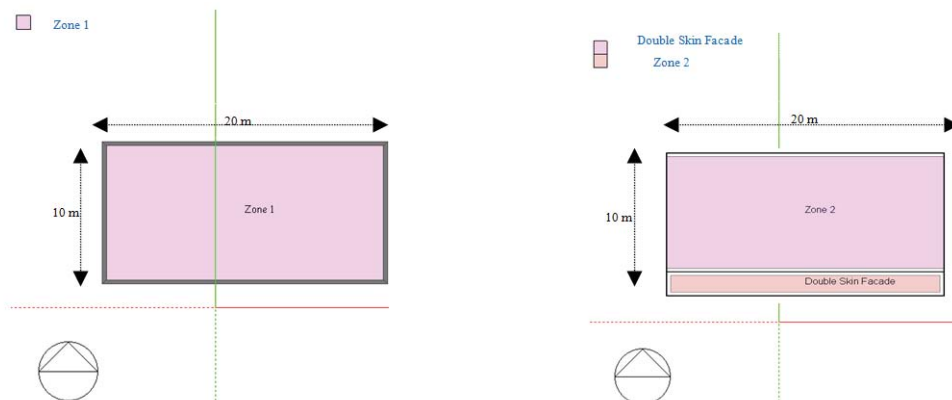


Figure 7. Architecture plans of Single Skin Façade (SSF) & Double skin façade (V.DSF), Design Builder Screen shoot.

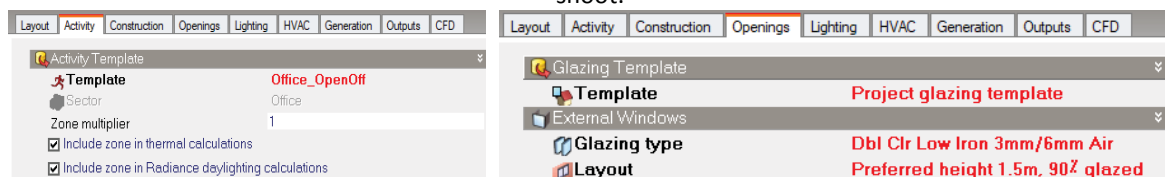


Figure 8. Set-points adaptation (18C°:24C°) & Façade Glazing System adaptation, Design Builder Screen shoot.

## RESULTS AND FINDINGS

The annual energy consumption of each Corridor Double-Skin Façade configuration examined within the office area of the building, In order to determine which Double-Skin Façade configuration and cavity airflow system is achieving the highest degree of efficiency in relation to energy consumption

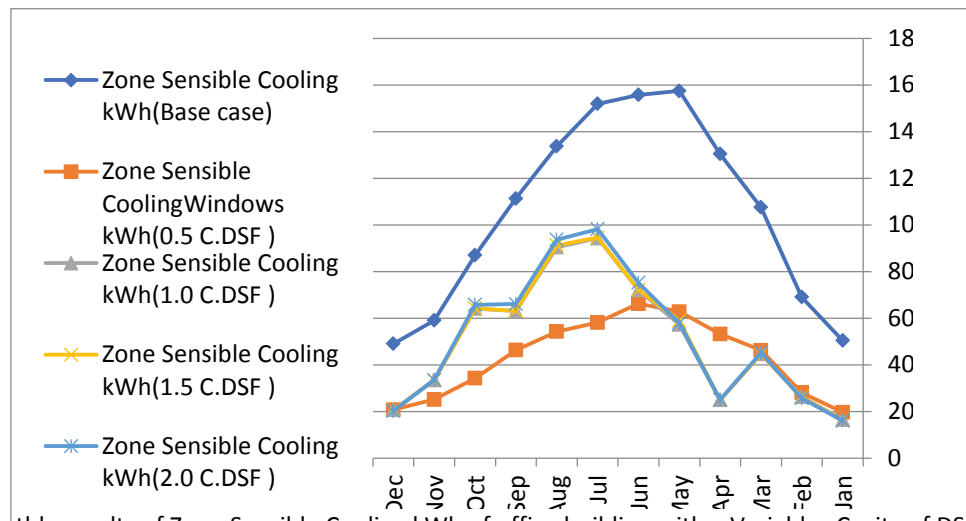


Figure 9. Monthly results of Zone Sensible Cooling kWh of office building with a Variables Cavity of DSF

Figure 9. Show Energy for Annual Sensible Cooling [kWh] for base case & Corridor Double-Skin Facades which show that the base case have the highest zone sensible cooling[kWh] ,0.5 m C.DSF achieve the lowest value while the 1.0m ,1.5m &2.0m C.DSF achieve the same zone sensible cooling [kWh] in June, July and August .

As shown from the graph the drop in April is due to the autumn and the lack of use of air conditioning systems in April.

Table 6. Annual Sensible Cooling kWh of office building with a Variables Cavity of Double Skin façade.

Energy for Annual Sensible Cooling [kWh]					
Month	Building without DSF	Corridor DSF (0.5m)	Corridor DSF (1.0m )	Corridor DSF (1.5m )	Corridor DSF (2.0m )
January	5040.99 kWh	1964.397 kWh	1649.235 kWh	1607.649 kWh	1600.317 kWh
June	15571.2 kWh	6623.073 kWh	7209.431 kWh	7207.336 kWh	7515.479 kWh
July	15189.1 kWh	5811.253 kWh	9430.306 kWh	9456.645 kWh	9816.107 kWh
August	13367.5 kWh	5425.12 kWh	9037.728 kWh	9119.288 kWh	9369.578 kWh

Result show that Corridor Double Skin Façade with a 0.5m cavity is the most efficient façade construction combination evaluated, this combination achieved an annual energy consumption value of 5811.253 Kwh which increase in efficiency of approximately 50% as opposed to the base model utilising a conventional single-skin façade 15189.12 kWh See (Table 6).

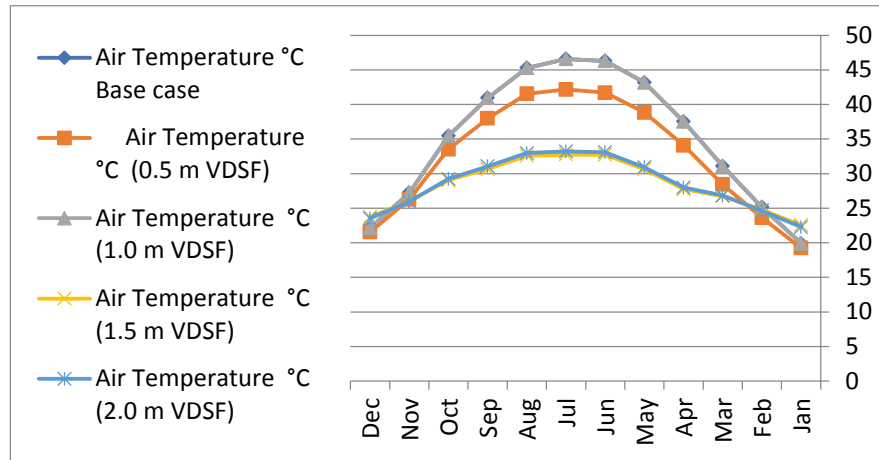


Figure 10. Annual results of Air Temperatures of Base-Case & Ventilated Double Skin Façade Model.

Table 7. Annual Sensible Cooling kWh of office building with a Variables Cavity of Double Skin facade.

	Outside air temperature °C	Building without Double Façade		Building with Corridor double Façade (2.0m )	
Month		Air temperature °C	Relative Humidity %	Air temperature °C	Relative Humidity %
January	13.745 °C	19.914 °C	50.93916	22.26075°C	46.93358
June	27.407 °C	46.30534 °C	11.68619	33.08418°C	31.01417
July	28.753 °C	46.56593 °C	11.47937	33.19928°C	32.89466
August	29.243 °C	45.28287 °C	12.26677	32.96633°C	32.46166

Results also showed that Annual Air Temperature of Single Skin Façade (SSF) was higher than other alternatives with a Double skin façade (V.DSF) model as shown in Fig 10, the graphical analysis show that the air temperature with 2.0m & ventilated corridor DSF 1.0 m achieved best enhancement with 33.19928°C in July while 0.5 & 1.0m corridor ventilated DSF increase air temperature equal to the base case model which have a highest air temperature See (Table 7).

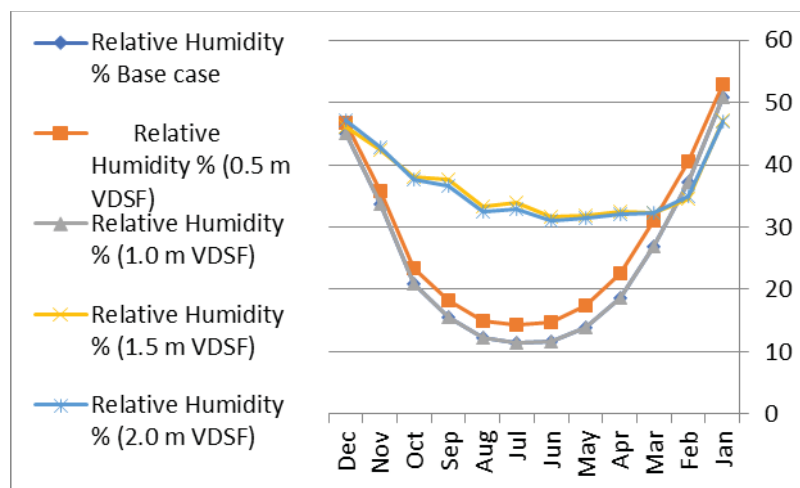


Figure 11. Annual Results of Relative Humidity of Base-Case & Ventilated Double Skin Façade Model.



Figures 11. Show the Relative Humidity values for Corridor DSF with 2.0m &1.5 m air cavity façade achieve best value with air temperature better than Corridor DSF with 1.0m ,0.5 m & BASECASE model.

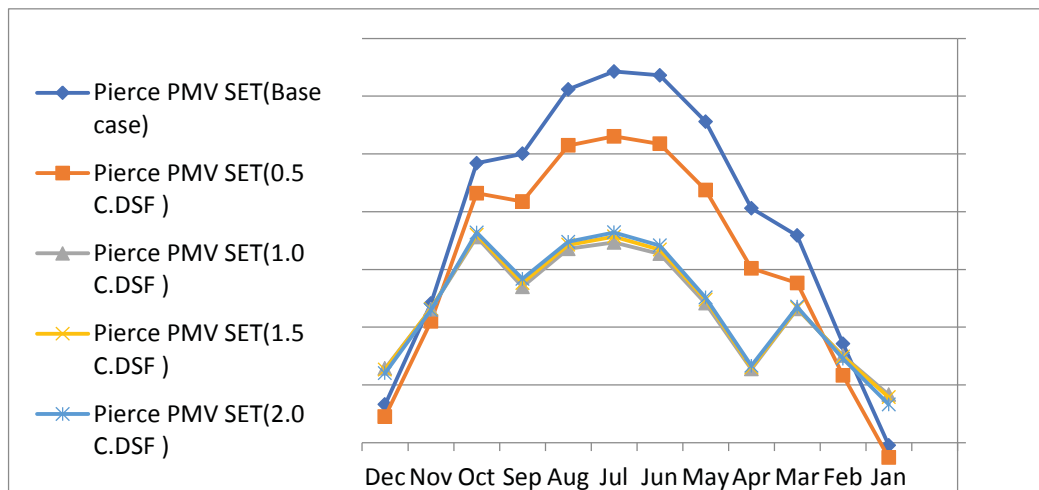


Figure 12. : Annual results of Pierce PMV (SET) of Base-Case & Ventilated Double Skin Façade Model.

Figures 12 show the Predicted Mean Vote (PMV) SET a method of describing thermal comfort developed by (Ole Fanger) for different façade alternatives that Corridor DSF with 2.0m air cavity façade has better thermal comfort condition than BASECASE model.

## Conclusion

By applying simulation using "Design-Builder" software of "Energy plus" simulation engine on "a Case- study" Model of an office building with two façade alternatives "Base-Case" (represent conventional "Curtain-wall" façade type) Model & (V.DSF) Model the research concludes the following results:

### ***With respect to (V.DSF) Saving Ratios of Energy Consumptions***

Application of (V.DSF) reduces the total energy consumptions due to both: (HVAC) ventilation & people occupancy by more than (50% till about 68%) with respect to correspondent "Base-Case" Façade type.

### ***With respect to Façade Orientations***

The lower energy consumptions of (V.DSF) orientations in descending arrangement was North (N).

### ***With respect to (V.DSF) Design Parameters***

"Air-Cavity" width: The larger "Air-Cavity" width, the lower energy consumption (but with little rate in reduction) after (50 cm) width.

Application of (V.DSF) type reduces the needed (HVAC) machines, and their Equipment Capacities with respect to the needed for the same building with correspondent single skin façade (conventional "Curtainwall" façade type).

"Glazing System" type: the more improving of (V.DSF) Glazing system the lower energy consumption. Ascending by improving: Layers (Single, double, triple), Type (Clear, Coloured, Reflected, coated with 'Low-E', Electrical) and Thickness (4, 6, 10 mm /pane), as a result of reducing glass (SHGC), U-value, and increasing Light Transmission Values (LT).

"External Skin" opening ratio: The larger "External Skin" ratio, the lower energy consumption (but with little rate in increasing) due to vanishing of "Stack-effect".

## References

- Azarbayjani, M. (2011). *Energy performance assessment of a naturally ventilated combined shaft-corridor DSF in an office building in Chicago*. PhD. University of Illinois at Urbana-Champaign
- Aokhamis, H. (2015). A state of art for using Double skin façade in hot climate, *4th International Conference on Environmental, Energy and Biotechnology*, 85(10), pp.10-7763
- Aaron Regazzoli . (2013). A Comparative Analysis On The Effect Of Double-Skin Façade Typologies On Overall Building Energy Consumption Performance In A Temperate Climate, DUBLIN INSTITUTE OF TECHNOLOGY , BSc Architectural Technology, Module: ARCH4258 – Final Year Dissertation.
- Chan ALS, Chow TT, Fong KF, Lin Z. (2009). Investigation on energy performance of double skin façade in Hong Kong. *Energy and Buildings*, 41(11), pp. 1135-1142
- Gratia E, De Herde A . (2004). Natural ventilation in a double-skin facade. *Energy and Buildings*, 36(2), pp. 137-146)
- Gratia E, De Herde A. (2007a). Are energy consumptions decreased with the addition of a double-skin? *Energy and Buildings*, 39(5), pp.605-619)
- Gratia E, De Herde A. (2007b). Greenhouse effect in double-skin facade. *Energy and Buildings*, 39(2), pp.199-211)
- Gratia E, De Herde A. (2007c). Guidelines for improving natural daytime ventilation in an office building with a double-skin facade. *Solar Energy*, 81(4), pp. 435-448)
- Gratia E, De Herde A. (2007d). The most efficient position of shading devices in a double-skin facade. *Energy and Buildings*, 39(3), pp.364-373)
- T. Boake, The Tectonics of the Double Skin :Green building or just more Hi-Tech , school of architecture , University of Waterloo.
- Ling, C. (2007). The Effect of Geometric Shape and Building Orientation on Minimizing Solar Insulation on High-Rise Buildings in Hot Humid Climate. *Journal of Construction in Developing Countries*, 12 (1), pp, 27- 38)
- Oesterle, E., Leib, R.D., Lutz, G., Heusler, B. (2001). Double skin facades: integrated planning: building physics, construction, aerophysics, air-conditioning, economic viability, Prestel, Munich
- Wong PC, Prasad D, Behnia M . (2008). A new type of double-skin façade configuration for the hot and humid climate. *Energy and Buildings*, 40(10), pp.1941-1945)
- Olesen ,B.W. (2005).Indoor Environment-Health-Comfort and productivity. International centre for indoor Environment and Energy, Technical University of Denmark. Lima 2005: [http://www.bine.info/fileadmin/content/Publikationen/Projekt-Infos/2010/Projektinfo\\_15-2010/11.pdf](http://www.bine.info/fileadmin/content/Publikationen/Projekt-Infos/2010/Projektinfo_15-2010/11.pdf)
- Poul O. Fanger: Thermal Comfort. Analysis and Applications in Environmental Engineering. Krieger, Malabar, Fla. 1982, ISBN 0-89874-446-6

# Dynamic lighting and cooling demand simulation in an urban context

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**Abstract:** The conventional building simulation method places the sensor at centre of the room to control the lighting output of the whole room without considering urban context. In the practical situation, sensors will be placed in a position that control a zone of light fixtures. This research aims to propose a new method for optimising the daylight sensor position in different urban contexts and creating a lighting output schedule from those sensors for use in dynamic building energy simulation. The model shows the most optimal position to place daylight sensor for each orientation and urban context and at which point more overshadowing increases energy consumption. This research also shows that building simulations without and with context can produce different results for energy consumption of up to 30%.

**Keywords:** parametric, daylight sensor position, building energy simulation

## Introduction

Lighting in office buildings is one of the design components that has effect on both lighting and cooling in term of energy consumption. Thailand is located in a warm and humid climate zone, which needs cooling to produce an environment to meet occupant satisfaction. Artificial lighting is needed to provide the necessary illuminance levels to meet the user needs, which contributes to the space cooling load due to the heat releases from light fixtures. So, reducing lighting loads also reduces the cooling load. The use of daylight can offset the level of artificial lighting, but this can incur solar gains that again may increase the space cooling load. Office design and the level of glazing therefore needs to be considered in the context of the balance between daylight, artificial lighting and solar gains, to provide a satisfactory energy efficient visual environment.

Previous research (Li and Lam 2001; Franzetti, et al. 2004; Ghisi and Tinker 2005; Krarti, et al. 2005; Li, et al. 2006; Roisin, et al. 2008) have shown that daylighting can help to reduce the needs for artificial lighting. However, only Franzetti, et al. (2004) takes into account of the cooling loads whereas others focus only on lighting loads. There are mainly three methods to estimate the potential for reducing lighting loads

## Field measurement

The first is the field measurement for lighting levels in actual buildings. Li and Lam have investigated the potential of a dimming control system by based on a case study office building in Hong Kong (Li and Lam, 2001). The research provided accurate result from empirical data collection. However, the research also illustrated limitations such as time frame, orientation and design variations. The measurements were carried out for four months from November to February with only North and South orientations. Li, et al. also used actual building in Hong Kong for measuring dimming control system (Li, et al., 2006). The measurements were carried out over seven months from February to August, with a single lighting sensor position in the measured office. These examples indicate that field measurement of light dimming control systems can provide accurate data but with limited constraints such as time frame of the measurement and the building configuration.

The field measurement method can also perform some real-world scenarios that is relatively complex to implement in simulation such as integrating user behaviour into the

variables (Aghemo, et al., 2014 and Chraibi, et al., 2016). Nevertheless, the results from the research are context-specific as Li, et al. (2006) has stated that the results are applicable only to the building with similar layouts and systems.

### ***Combined field measurement and building simulation***

The second method is a combination of field measurement and building simulation. Research (Franzetti, et al. 2004; Ghisi and Tinker 2005) have shown the use of field measurement to validate the results from simulation to increase the reliability with empirical data measurement. Ghisi and Tinker (2005) have extensively shown the potential of using the simulation program, VisualDOE, for thermal simulation and daylight, using the daylight factor calculation method proposed by Hopkinson, et al. (1996). Daylight factor calculation can be carried out for a range of reference points in a space, and compared to measurements at a light sensor position, by taking into account of the sky component, the external reflected component and the internal reflected component. The simulation was performed with 1,100 cases consist of 5 room ratios, 10 room dimensions, 11 window sizes and in two locations, Leeds (UK) and Florianopolis (Brazil). The research shows relatively reliable results using VisualDOE, with an average of 0.4% difference from field measurements. Daylight measurements were performed over four days during February on the roof of the Civil Engineering Building, University of Leeds, UK. Frenzetti, et al. (2004) used a slightly different approach for validating daylighting result. Daylighting calculations were carried out using the LIGHT calculation module. The validation was achieved by comparing lighting levels from LIGHT with measured lighting levels from the laboratory located in Research Centre of EDF, Les Renardieres, France. The results showed a good correlation rate of 0.9 for lighting levels below 1,000lux, which is in the range that has impact on dimming control system. This comparison was carried out to validate the LIGHT calculation module, which Frenzetti, et al. (2004) used later in the research to simulate daylighting levels in various scenarios.

### ***Pre-validated building simulation***

The third method for investigating a dimming control system is to use a pre-validated building simulation program. Roisin, et al. (2008) has shown the use of a simulation program to the extent that simulates lighting levels for Brussels, Stockholm and Athens with six variations of control system for all four directions of North, South, East and West. The lighting simulation was carried out using Daysim, which as Rosin et al. (2008) has been validated in a number of previous research studies (Reinhart and Herkel 2000; Reinhart and Walkenhorst 2001). Bodart and Herde (2002), Krarti, et al. (2005) and Roisin, et al. (2008) have also shown the capabilities of using a simulation program to analyse various variables such as shapes, window sizes, orientations and locations.

Roisin, et al. (2008) has shown a relatively high lighting energy saving that ranges from 45 to 61%. Each light fixture in the research has its daylight sensor. This practice can produce the highest energy reduction possible. However, this may be unpractical for an open plan office to have a daylight sensor for every light fixture.

Bodart and Herde (2002) also shows a high lighting energy reduction from 50 to 80%. Bodart and Herde stated that it was because “the light sensor is located in the center of the room.”. Placing daylight sensor at the centre of the room to control the whole room causes the deeper area away from the window to have the light intensity lower than the setpoint. Hence, the larger the room the higher the reduction. Mistrick, et al. (2000) has also shown

an extensive use of Daysim with two lightsensor positions coupling with twenty-tree conditions to test eight different daylight sensor behaviours

Table 1: Shows more details of how different methods were performed

Research	Method	Model	Lighting System	Context
Li and Lam, (2001)	Field measurement	Width 2.8m x Length 4.5m x Height 2.4m Facing North and South	<ul style="list-style-type: none"> <li>- Two light sensors per room. A sensor controls two or three light fixtures.</li> <li>- From November 1999 to February, March and April 2000</li> </ul>	Fixed context
Li, et al., (2006)	Field measurement	Width 10.29m x Length 5.88m x Height 2.39m Facing North West	<ul style="list-style-type: none"> <li>- One light sensor controls a zone</li> <li>- From February to August 2004</li> </ul>	Fixed context
Franzetti, et al., (2004)	Mixed	Width 3m x Length 6m x Height 2.35m Facing North, East and South	<ul style="list-style-type: none"> <li>- LIGHT</li> <li>- Laboratory measurement was performed to compare with result from LIGHT</li> <li>- Nine light sensors across the room</li> </ul>	Clear
Ghisi and Tinker, (2005)	Mixed	2:1, 1.5:1, 1:1, 1:1.5 and 1:2 room ratios Facing North, South, East and West	<ul style="list-style-type: none"> <li>- BRS Simplified Daylight Table</li> <li>- Light sensor at the centre of each 50cm x 50cm grid across the room</li> </ul>	Clear
Krarti, et al., (2005)	Simulation	Width 3.8m x Length 3.7m x Height 2.7m Facing North, South, East and West	<ul style="list-style-type: none"> <li>- DOE-2.1E</li> <li>- Light sensor at centre of the room controls the whole room.</li> </ul>	Clear
Roisin, et al., (2008)	Simulation	Width 3.05m x Length 6.55m x Height 3.05m WWR 33% Facing North, South, East and West	<ul style="list-style-type: none"> <li>- Daysim</li> <li>- One light sensor controls one light fixture</li> </ul>	Clear



The development report and case studies from Architectural Energy Corporation (AEC, 2006) introduces the Sensor Placement Optimization Tool (SPOT) which has the option to generate the optimal photosensor positions. In the SPOT program, there is a button stated 'Auto-Generate Photocell Position'. However, what it does is performing correlations between the illuminance of selected point in the zone and the illuminance of 315 ceiling grid points. According to the SPOT Version 5.0 User's Manual (Daylighting Innovations), the position generated from the auto-generate sensor position would be the default location. This method is useful to the ceiling type photosensor with the selected point represents the specific working position.

### **Problem statement and aim**

Across the three methods previously explained, there are three main practices to control lighting output from daylight sensor. See Table 1.

1. A single sensor located at the centre of the room which controls the lighting for the whole room. Simulation methods often use this practice to estimate the energy reduction from utilising daylighting. However, positioning the sensor at centre of the room, to control the lighting output for the whole room, will generally result in the deeper area of the plan having a light intensity lower than the required set-point. Moreover, the inefficiency of a sensor increases as the sensor has less sky-view angle (Bodart and Herde, 2002), which implies that the sensor should be closer to the window to increase its efficiency.
2. A single sensor controls one light fixture above it. This practice is also sometimes used in simulation-based research (Rosin, et al. 2008). This practice often results in a high energy reduction rate, although, it is not often used in an open plan office where the location of office desks are not known or often move around.
3. A single sensor controls a zone of light fixtures. This practice is widely used in real world situation and field measurement-based research. Nevertheless, results are often case-specific and less generalise comparing to practice a and b, as seen in Table 1 that the room sizes are small and the time frame spans only a few months.

For simulation-based research, positioning the lighting sensor other than at the centre of the room or at the centre of every grid points across the room is hard to determine because there is no guideline for it yet. Furthermore, context, which should play a major role, is often excluded from the simulation. These two notions have led to the research described in this paper, which aims to propose a new method for optimising the daylight sensor position in different urban contexts and creating a lighting output schedule from those sensors for use in dynamic building energy simulation.

### **Methodology**

There are two steps in this research. The first is to find an optimum position of daylight sensor and establish the parameter of the circuit. The second is to use the selected sensor position and the zone each sensor controls in energy simulation. The research has considered 115 configurations, using two sets of variables. The first set is a range of window areas, namely, 20%, 40%, 60%, 80% and 100%. The second set of variables is the urban context configurations of surrounding buildings, with some 23 configurations of heights of surrounding buildings.

To achieve the aim, this research has used a parametric modelling tool called Rhinoceros and Grasshopper (McNeel, 2007) to investigate energy consumption (lighting

and cooling) from different lighting sensor positions and building configurations. The Ladybug and Honeybee plug-in is used to connect the model with Daysim for daylighting simulation (Roudsari, et al., 2013). The results from Daysim are then transferred to grasshopper to optimise daylight sensor position. These positions are used to create lighting output schedules parametrically using a meta-file to create text-based input for dynamic building energy simulation, using the HTB2 building energy model (Lewis and Alexander, 1990). The details are explained in following sections.

### **Model**

A high-rise office with a typical floor plan of 40 x 40 m with a 3.5 m floor to floor height has been studied (Chirarattananon and Taveekun, 2004; Kofoworola and Gheewala, 2008; Yanwaisakul and Sreshthaputra, 2013). Wall to window ratios (WWR) range from 20% to 100% in 20% steps. The space has five zones; facing North, South, East, West and a 20 x 20 m core.

### **Context conditions**

The urban context condition used in this research is Bangkok, Thailand. According to the building regulation (Ministerial Regulation No.55 (B.E. 2543) (A.D. 2000)), high-rise building has to have at least 6 metres set-back from the site boundary. The condition can be simplified into the context factor (1). The increment of the factor starts at 0.5 and increases in 0.5 steps, which represents the height of surrounding building at 6 meters and distance at 12 meters to the *CF* at 11.5 which represents the height of surrounding building at 138 meters (40 storey) and distance at 12 metres.

$$\text{Context Factor (CF)} = \Delta H/D \quad (1)$$

where:  $\Delta H$  = difference in height between the zone and surrounding building;  $D$  = distance between the buildings.

### **Finding daylight sensor positions**

Light intensity near the window or light source is always higher than the further from the window or the light source. This behaviour means that if the light intensity at the given point is above the set point, the area closer to the window would always have the light intensity over the set point. This notion means it is reasonable to have a sensor control the area closer to the window but not deeper since the deeper area would have lower light intensity than the set point. Li D.H.W., et al. (2006) has also used daylight sensor to control parameter with this logic but the sensor position was not placed at the most optimal position.

$$DPV = 1; \text{ if light intensity is above the setpoint} \quad (2)$$

$$DPV = \text{light intensity/setpoint}; \text{ if light intensity is below the setpoint}$$

For the first step in this research, test points are placed every 0.5m starting from 0.25m distance from the window at 0.75m above the floor. Annual daylight simulation was performed by using Daysim through Honeybee. Then, the light intensity of each test point is converted to daylighting potential value (*DPV*) by dividing by 500, if the intensity is below 500lux. If the intensity is above 500lux, the daylight potential value is 1.0, where 500lux is the lighting set-point (2). This conversion gives out the daylight potential value for

positioning daylight sensor which would be at the point with the highest value. All daylight potential values for the whole year are added together for each point. Each point then multiplies with the area that it would control the lighting output (3). The result then shows that although the test point that is closer to the window has higher daylight potential value but with smaller area it covers, its true potential after multiplication is lower than other positions with lower daylight potential value but higher coverage area (Figure 1).

$$\text{True Potential} = A * DPV \quad (3)$$

where:  $A$  = the area that the daylight sensor controls the light circuit;  $DPV$  = Daylight potential value

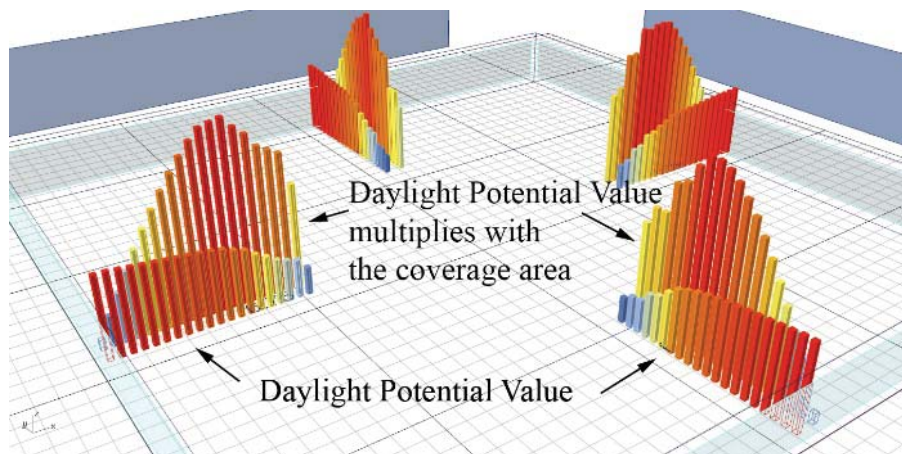


Figure 1: Shows the visual of daylight potential value on each testing *point*

The daylight sensor positions and the zone that each one covers are selected from the position with the highest value for each orientation and each *CF*.

This study uses Grasshopper and Honeybee to perform the lighting simulation for various reasons. The first and foremost is the coupling between Grasshopper that can perform brute force to number sliders which will initiate all simulations at one go and Daysim that export the result of each simulation into \*.ill files, which are text files, in each separated folder. The authors then ran a Python script to read the results from \*.ill files later without interrupting the continuing daylight simulation. Running each task separately reduces the amount of time to fix the error if occurs.

Grasshopper is also capable for reading the result back to create visualisation such as shown in Figure 1 or, in this study, to create schedules for performing energy simulation later in HTB2s.

### ***Schedule and power output***

This research uses schedule profiles for from ASHRAE 90.1 (2013). The lighting schedule for dimming control zone was created from combining the factor from lighting output ranges from 0.1 when the light intensity is at 500lux or higher and at 1.0 when the intensity is at 0lux. The output factor from daylight intensity is only used for 8-12 and 13-18 hour of weekday. The rest of the hours use ASHRAE 90.1 (2013) which lighting schedule was added with 5% emergency lighting. ASHRAE 90.1 (2013) also provides lighting schedule with occupancy sensor but occupancy sensor is not within the scope of this study.

Power outputs in this study are 8W/m<sup>2</sup>, 10W/m<sup>2</sup> and 70W/person for lighting, equipment and occupancy with 10m<sup>2</sup>/person (CIBSE, Guide A, 2006). Total energy consumption consists of the on-site consumptions (end-uses) of lighting, cooling and equipment.

### ***Energy simulation***

The second step of this study is to perform the dynamic energy simulation to see the result of this daylight positioning method in context. The modelling consists of five zones per floor with two lighting circuits, dimmable and non-dimmable, for North, South, East and West. The areas of each dimming control zone for each window size and CF are different as well. HTB2 was used for performing building energy simulation for various reasons such as, the model is in a text format which is relatively easy to make changes and create cases parametrically. HTB2 is also able to handle the dynamic change of lighting schedule because the way HTB2 controls the of power outputs.

In HTB2, the power output of each lighting circuit is specified by the total amount of power output not by the area and one zone can also have multiple circuits. This feature allows model of the zone to be the same but only change the amount of power output for dimming control circuit and non-dimming control circuit. The schedule of each circuit is specified within the lighting file using the factor where 1.0 is 100% and 0 is 0% power output. Furthermore, the schedule can be override for more detailed control in DIARY files, where each DIARY file contains the schedule of each day with in the year.

Since HTB2 uses text-based files for modelling, they can be produced by using meta-file method (Fragaki, et al., 2008). The authors used python, a programming language, to create scripts that produce HTB2 files from meta files. All simulations were run by using one batch file that was created later according to the directory of HTB2 files.

Fragaki, et al. (2008) and Glazer (2016) show that EnergyPlus, a building energy simulation program, can also perform a similar technique. However, in this study, HTB2 has some advantages over EnergyPlus. EnergyPlus file is a single IDF file, whereas HTB2 files are separated into smaller files. One HTB2 file contains only a few lines of information. This characteristic allows HTB2 files to be created from meta files more efficiently because the script does not have to go through many lines to modify the target variables. Some HTB2 files that has no change can be copied and pasted in to the destination folders right away. DIARY files in HTB2 create schedule for each day. EnergyPlus can also have each schedule for each day but with more complexity and a larger IDF file.

In summary, HTB2 and meta-file method allow authors to create models and run simulations with minimal effort.

### ***Limitation***

The major limitation in this work is that the study did not include the blinding in one of the variables. The authors are aware of the blinding feature that is already existed in DAYSIM. However, the use of blinding depends on either glare or energy intensity, 50 W/m<sup>2</sup>, on a given point is generally tested in closed plan space. This research used open plan space as a case study which is different in characteristic. Moreover, the main aim of this research is to propose a new method for optimising the daylight sensor position in different urban contexts. Blinding and any type of shadings are outside the scope of this research.

## Results and discussion

While the aim of this research is to propose a new method for optimising the daylight sensor position and creating schedule for building simulation, the energy consumption is a byproduct of the methodology. Hence, there are three aspects of results the authors would like to present; position of the sensor under different configurations, relationship of lighting load and cooling load and the last is the performance of total energy consumption.

### *Daylight sensor position*

Table 2 shows nearest and furthest daylight sensor positions for the lowest and the highest *CF* of each orientation and WWR. The daylight sensor position ranges from 6.75m for the South side with a 100% WWR with 0.5 *CF* to 0.75m for West, South and East with 20% WWR with a 11.5 *CF*. The result also shows that 80% and 100% WWR have the same sensor positions. This is because the larger window area from 80% to 100% WWR does not increase sufficient daylight potential value and also perform worse for overall energy consumption due to more solar heat gains through the window. Another reason 100% WWR has the same sensor positions as 80% WWR is because the limit of the height of the window. This means that if the shape is taller, it is possible that the sensor could be deeper.

The daylight sensor positions are closer to the window when overshadowing increases at a different rate for different orientations. However, at around *CF* 3.0 to 5.5, all orientations have the same depth of the sensors (Figure 2). This behaviour happens because the sensor starts to receive only diffuse daylight which is the same in all directions. All WWRs have similar characteristic with the example of 60% WWR in Figure 2 because the size of the window only determines the amount of daylight coming through, which similar to having higher *CF*.

Table 2: Shows closest and furthest daylight sensor position depth from window in metre (m)

WWR	CF	North	South	East	West
20	0.5	1.75	1.75	1.75	1.75
	11.5	1.25	0.75	0.75	0.75
40	0.5	3.25	3.25	3.25	3.75
	11.5	1.75	1.75	1.75	1.75
60	0.5	5.25	5.25	5.25	5.25
	11.5	2.75	2.75	2.75	2.75
80	0.5	6.25	6.75	6.25	6.75
	11.5	3.25	3.25	3.75	3.25
100	0.5	6.25	6.75	6.25	6.75
	11.5	3.25	3.25	3.75	3.25

### *Relationship of lighting load and cooling load*

More overshadowing from urban context, higher *CF*, increases lighting load from lesser daylighting availability and at the same time decreases cooling load from lesser solar gain. However, lighting load starts to overtake cooling load around *CF* 2.0 to 3.0 as shown in Figure 3 where Cooling + Lighting starts to incline.

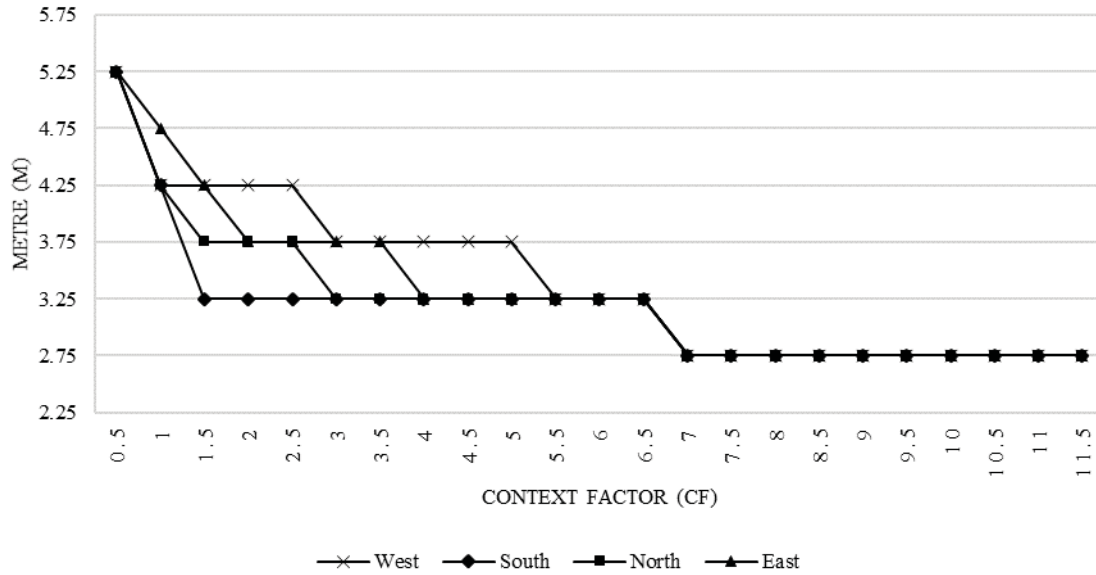


Figure 2: Shows sensor positions for WWR 60% with different CF

Figure 3 also shows another crucial notion which was stated in previous section that doing building simulation without context can lead to a difference. The result shows that the case with higher WWR has higher different in energy load between CF 0.5 and 11.5. The different from lighting load can be up to around 30%, 30%, 25%, 15% and 10% for WWR at 100%, 80%, 60%, 40% and 20%, respectively. Cooling loads also show similar differences from 10% to 25%. The result correlates with Samuelson, et al., (2016) which says that the different in energy consumption from building simulation between with and without-context ranges from 8 to 31%.

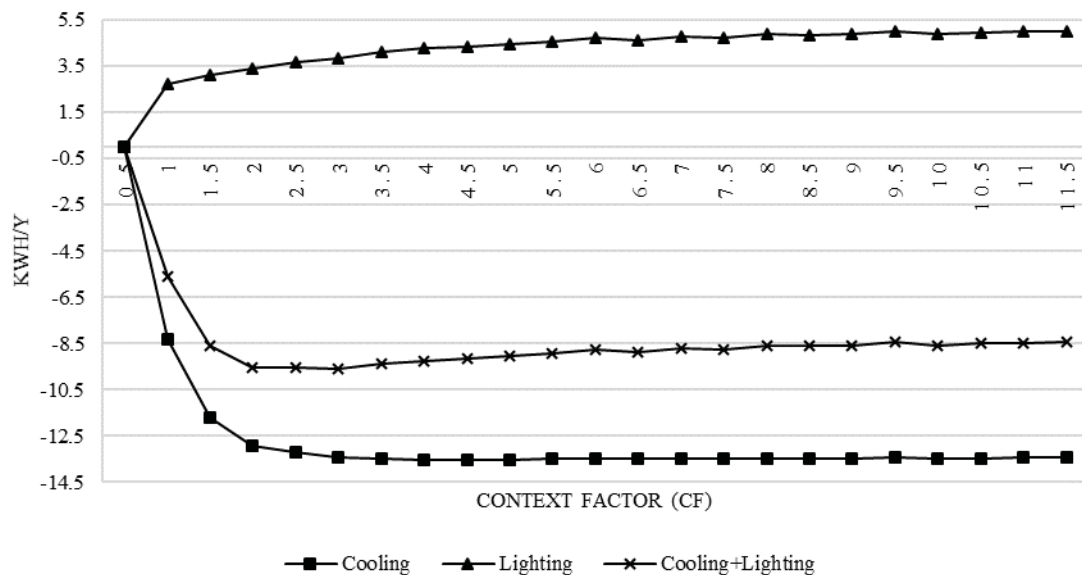


Figure 3: Shows energy consumption of cooling, lighting and both cooling + lighting

### Total energy consumption

Total energy consumptions from all orientations with daylight sensor show similar characteristic which the consumptions drop to a certain point and then start to incline (Figure 4). The result shows that the lowest energy consumption is reached when the CF is



around 2.0 to 3.5 then, the consumption increases as overshadowing increases. This is caused by the increased level of lighting loads preceded by a reduction in cooling load from overshadowing as shown in Figure 3.

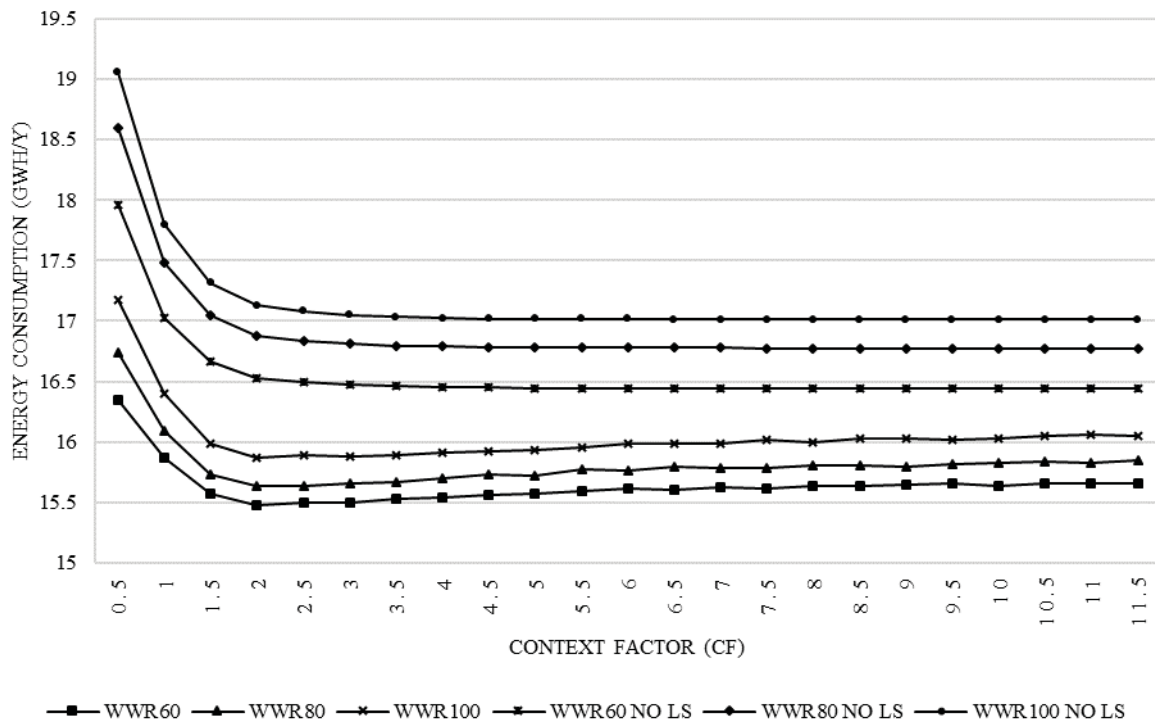


Figure 4: Shows total energy consumption of cases with and without light sensor

The energy consumption from 100% WWR is higher than 80% WWR with the same daylight sensor positions means that the exceeded energy consumption comes from the heat gain through fabric with a little to no benefit from daylighting.

Figure 4 also shows the different between cases with daylight sensor and without daylight sensor. The result shows that implementing daylight sensor reduces more energy than decreasing window size even at the high CF. The reductions for cases without daylight sensor are purely from overshadowing which continue to decrease but with a slower rate as CF increases.

## Conclusion

The aim of this research is to propose a new method for optimising the daylight sensor position within the different urban contexts and creating a lighting output schedule from those sensors for use in dynamic building energy simulation. This has reflected the aim by first, reviewed some literatures which show that there are some problems and limitations with implementing daylight sensor in both simulation-based and field measurement-based research.

Then, the methodology was formed into two steps. Frist is to find the most optimal position for placing the daylight sensor and then perform building energy simulation to see the result in different contexts.

The first step shows that daylight sensor position is closer to the window when there is less daylight availability either from overshadowing or smaller window area. The position

depths from the window ranges from 0.75m to 6.75m depends on the orientation, window size and context.

The results show that the area of the building with a  $CF$  less than 2 should improve its overshadowing until it reaches the same as  $CF$  of 2. On the other hand, the area with a  $CF$  more than 2 should consider improving daylight utilisation to reduce lighting loads and cooling loads.

This research also shows that building simulations without and with context can produce different results for energy consumption of up to 30%.

### Recommendations for further work

This daylight sensor positioning method should be tested against other methods such as one sensor per one light fixture in various dimensions especially the cost efficiency of the system.

The method should be investigated with wider range of variables such as external shadings and contexts or couple with behavioural models (Bourgeois, et al., 2006). There might be the point where daylight sensor is not sufficient to implement anymore. There might also be the situation with some fabric materials or different lighting power levels that the daylight sensor is not cost effective anymore.

### References

- Aghemo, C., Blaso, L. and Pellegrino, A. (2014). Building automation and control systems: A case study to evaluate the energy and environmental performances of a lighting control system in offices. *Automation in Construction*, 43, pp. 10 – 22
- Architectural Energy Corporation (2006). *Daylighting Metric Development Using Daylight Autonomy Calculations In the Sensor Placement Optimization Tool: Development Report and Case Studies*.
- Bodart, M. and Herde, A.D. (2002). Global energy savings in offices buildings by the use of daylighting. *Energy and Buildings*, 34(5), pp. 421 – 429.
- Bourgeois, D., Reinhart, C., and Macdonald, I. (2006). Adding advanced behavioural models in whole building energy simulation: A study on the total energy impact of manual and automated lighting control. *Energy and Buildings*, 38, pp. 814 – 823.
- CIBSE, G.A. (2006). *Environmental design*. The Chartered Institution of Building Services Engineers, London.
- Chirattananon, S. and Taveekun, J. (2004). An OTTV-based energy estimation model for commercial buildings in Thailand. *Energy and Buildings*, 36(7), pp. 680 - 689.
- Daylighting Innovations. SPOT – Sensor Placement and Optimization Tool. <https://www.daylightinginnovations.com/spot-download>
- Chraïbi, S., Lashina, T., Shrubsole, P., Aries, M., Loenen, E.V. and Rosemann, A. (2016). Satisfying light conditions: A field study on perception of consensus light in Dutch open office environments. *Building and Environment*, 105, pp. 116 – 127.
- Fragaki, A., Alexander, D., Jones, P., Lannon, S. and Smith, A. (2008). Input dataflow management for the simulation of community energy use. In: *PLEA 2008 – 25<sup>th</sup> Conference on Passive and Low Energy Architecture*, Dublin, Ireland, Oct 2008.
- Franzetti, C., Fraisse, G. and Achard, G. (2004). Influence of the coupling between daylight and artificial lighting on thermal loads in office buildings. *Energy and Buildings*, 36(2), pp. 117 – 126.
- Ghisi, E. and Tinker, J.A. (2005). An Ideal Window Area concept for energy efficient integration of daylight and artificial light in buildings. *Building and Environment*, 40, pp. 51 – 61.
- Glazer, J. (2016). USING PYTHON AND EPPY FOR A LARGE NATIONAL SIMULATION STUDY. *IBPSA-USA Journal*, 6(1), pp. 230 -237.
- Hopkinson, R.G., Petherbridge, P. and Longmore, J. (1966). *Daylighting*. Heinemann.
- Krarti, M., Erickson, P.M., Hillman, T.C. (2005). A simplified method to estimate energy savings of artificial lighting use from daylighting. *Building and Environment*, 40(6), pp. 747 – 754.

- Kofoworola, O.F. and Gheewala, S.H. (2008). Environmental life cycle assessment of a commercial office building in Thailand. *The International Journal of Life Cycle Assessment*, 13(6), pp. 498 - 511.
- Lewis, P.T., Alexander, D.K. (1990). HTB2: A Flexible Model for Dynamic Building Simulation. *Building and Environment*, 25(1), pp. 7 - 16.
- Li, D.H.W. and Lam, J.C. (2001). Evaluation of lighting performance in office buildings with daylighting controls. *Energy and Buildings*, 33(8), pp. 793-803.
- Li, D.H.W., Lam, T.N.T. and Wong, S.L. (2006). Lighting and energy performance for an office using high frequency dimming controls. *Energy Conversion and Management*, 47(9), pp. 1133 – 1145.
- McNeel, R. (2007). RHINOCEROS®: NURBS modeling for Windows [Computer software]
- Ministerial Regulation No. 55 (B.E. 2543) (A.D. 2000) issued under the Building Control Act 2552 Act.
- Mistrick, R., Chen, C.H., Bierman, A. and Felts, D. (2000). A Comparison of Photosensor-Controlled Electronic Dimming Systems in a Small Office. *Journal of the Illuminating Engineering Society*, 29(1), pp. 66 – 80.
- Reinhart, C.F. and Herkel, S. (2000). The simulation of annual daylight illuminance distributions—a state-of-the-art comparison of six RADIANCE-based methods. *Energy and Buildings*, 32(2), pp. 167 - 187.
- Reinhart, C.F. and Walkenhorst, O. (2001). Validation of dynamic RADIANCE-based daylight simulations for a test office with external blinds. *Energy and buildings*, 33(7), pp. 683 - 697.
- Roisin, B., Bodart, M., Deneyer, A. and D’Herdt, P. (2008). Lighting energy savings in offices using different control systems and their real consumption. *Energy and Buildings*, 40(4), pp. 514 – 523.
- Roudsari, M.S., Pak, M. and Smith, A. (2013). Ladybug: a parametric environmental plugin for grasshopper to help designers create an environmentally-conscious design. In: *Proceedings of the 13th International IBPSA Conference*, Lyon, France Aug.
- Samuelson, H., Claussnitzer, S., Goyal, A., Chen, Y. and Romo-Castillo, A. (2016). Parametric energy simulation in early design: High-rise residential buildings in urban contexts. *Building and Environment*, 101, pp. 19 – 31.
- Standard, A.S.H.R.A.E., Standard 90.1-2013. *Energy Standard for Buildings Except Low-Rise Residential Buildings*.
- Yanwadsakul, P., Sreshthaputra, A. (2013). Guidelines for Increasing Energy Efficiency of Large Government Office Buildings by Improving Building Envelope Materials. *Built Environment Research Associates Conference, BERAC 4*, pp. 62 – 69.

# Investigation of strategies for optimal retrofitting of London Victorian houses to prevent overheating

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**Abstract:** Climate change predictions determine the building industry to reduce carbon emissions and prevent indoor overheating risk. Future weather files predict high temperatures in London, with an increase in the heatwaves frequency. The 2003 and 2006 heatwaves led to a high number of deaths across Europe, including in the UK. Without improved design or mechanical cooling, these high outdoor temperatures transfer to the buildings' indoor environment, impacting on inhabitants' thermal comfort and health. As 75% of existing housing stock will still be standing by 2050 (SDC, 2006), it becomes paramount to retrofit them optimally. Pre-1919 Victorian houses represent 20% of existing London buildings (DCLG, 2015). Reaching new building standards on overheating and avoiding CO<sub>2</sub> emissions due to mechanical cooling requires retrofitting the existing buildings, with focus on using passive design solutions on walls and windows. This paper investigates passive retrofitting strategies to identify optimal solutions to prevent overheating risk in London Victorian houses, without increasing carbon emissions through air conditioning. The strategies involve single and combined solutions for fabric (external/internal insulation) and glazing (triple-glazing and 50% reduction of the windows' area). Two occupancy profiles were considered: 18:00-08:00 working professional, and 24-hour. The occupancy pattern was significant in terms of the exposure time and temperatures, the 24-hour users being more affected by overheating. The rooms investigated are two south-west-facing bedrooms on the first and second floors, for difference in level. The results showed that the most efficient methods for preventing overheating referred to glazing, by replacing double-glazing with triple-glazing, and especially the 50% windows reduction strategy, the less efficient ones referring to the fabric, external and internal insulation, with the internal insulation the least recommendable. The second floor bedroom had generally slightly lower temperatures, with potentially different results for higher height differences.

**Keywords:** overheating, retrofit, passive design, existing buildings, energy efficiency

## Introduction

This study aims to explore through computer modelling retrofitting strategies to prevent overheating in Victorian houses to make them adapted to future climate change scenarios, as per UKCP09. IPCC (2014) predicts that there will be more hot temperature extremes worldwide, a higher frequency of heatwaves with longer durations. Another imperative for the building environment is to respond to the 2050 80% CO<sub>2</sub> emissions reduction demands committed through the 2008 Climate Change Act, 2010 Energy Performance of Buildings Directive, 1998 Kyoto Protocol. These desiderates can be fulfilled through methods like passive retrofitting solutions applied to the wall fabric (internal and external insulation) or glazing (by replacing the current double-glazing windows with triple-glazing and/or reducing the current windows' area on the walls). The strategies are applied to external walls of the bedrooms facing south-west on the first and second floors in a shared mid-terrace house in East London. They are the most sun-exposed rooms. The thermal comfort of the inhabitants is evaluated through overheating risk criteria set by CIBSE. The study is also interested in identifying if there is any difference between the two bedrooms' thermal behaviour based on the height they are on. The occupancy profiles consider two types as relevant: a 24-hour occupancy, applicable to children, aging population and people with severe health conditions, and an 18:00-8:00 one, corresponding to the outside the office hours for

professionals in full-time employment, as opposed to the 8:00-18:00 hours pattern used by studies regarding overheating risk in offices (Oseland, 1995; Goia, 2016). The paper reviews relevant literature and discusses the necessity of assessing overheating, its definition and criteria to assess it, and retrofitting strategies. The modelling and simulation are performed in IES and the resulted data manipulated in Microsoft Excel. The results and discussion parts at the end assess and interpret the outcomes of the research. They reveal the importance of glazing manipulation in preventing the overheating risk, as the best scenarios came from glazing manipulation by replacing double-glazing with triple-glazing and reducing the windows size by 50%, the best result being obtained when these strategies are combined. For the fabric solutions the internal insulation has proved to be the less efficient scenario. This paper's results are constrained by the limitations described in the Conclusions.

## **Climate change**

The climate change research (IPCC, 2014) has shown that the future may trigger a rise in the average temperatures. There is a bidirectional relation between buildings and climate change: the increase of temperatures due to climate change impacts on the buildings' indoor environment (CIBSE, 2013), and thus on people's health and wellbeing (Porritt et al., 2011; Mavrogianni et al., 2012), and the energy inefficient buildings contribute to the increase of CO<sub>2</sub> emissions, and therefore to climate change (Oraiopoulos et al., 2015, Hacker et al., 2005). A healthy indoor environment is crucial, as, due to technology, people spend around 80% of the time indoor (Crump, 2011), mainly at home (Schweizer et al., 2007). By 2080 the central estimates of the average summer temperatures rise by 3-4°C (DEFRA, 2009; Murphy et al., 2009), with a high increase in the frequency of heatwaves (Jones et al. 2008).

## **Thermal stress**

When the thermal environment impacts on health (CIBSE, 2010), thermal discomfort becomes thermal stress. As people respond differently to thermal stimuli, predicted mean vote (PMV) "predicts the mean value of the votes of a large group of persons" in similar conditions (BSI, 2005; CIBSE, 2015). Predicted percentage of dissatisfied (PPD) predicts "the proportion of any population that will be dissatisfied with the environment" (extreme PMV scores on the ASHRAE scale (CIBSE, 2013; BSI, 2005). For indoor thermal comfort the recommended PMV is between -0.5 and +0.5 on the ASHRAE scale (BSEN 15251:2007) and the acceptable PPD is less than 10% dissatisfied people (BSEN 15251:2007).

## **Overheating**

Overheating happens when the "building occupants feel uncomfortably hot" in one instance or over a period, due to the indoor environment, as "the temperature in the building is too high for comfort" (CIBSE, 2013). It is associated with lack of air movement and related to the exposure time. Nicol et al. (2012) criticise this definition for missing aspects such as: emphasis on the free-running buildings, dependant on the environment, insufficient accuracy of the thermal criterion used for appreciating overheating, and omitting factors like room size, ventilation, number of occupants. In practice, overheating is defined by determining a certain temperature above which a specific percentage of the population vote +2 or +3 on the ASHRAE scale (CIBSE, 2013), involving a certain amount of overheating hours above the threshold temperature (CIBSE Guide A, CIBSE TM36, CIBSE TM59). Overheating impacts on human health (IPCC, 2014; Oraiopoulos et al., 2015), whilst also

contributes to the increase of the energy consumption through cooling (Oraiopoulos et al., 2015; Hacker et al., 2005) and thus of the CO<sub>2</sub> levels, contravening to the UK's commitments.

### ***Criteria for defining overheating in free-running buildings***

The relativity of all the factors involved in thermal comfort evaluation makes it difficult to assess overheating in buildings and only recently an instrument has been developed through the creation of *CIBSE TM59* drawn on *CIBSE TM52* (2013) and *CIBSE Guide A* (2015). This provides the methodology for assessing overheating in high-rise buildings, but also applicable to houses. Thus for naturally ventilated buildings both of the following conditions must be met for bedrooms: "the number of hours during which  $\Delta T$  is greater than or equal to one degree (K) during the period May to September inclusive shall not be more than 3 per cent of occupied hours" and the operative temperature in the bedroom from 10 pm to 7 am shall not exceed 26°C for more than 1% of annual hours" (CIBSE, 2017). The *CIBSE Guide A* recommends the summer operative summer 23-25°C for bedrooms, with overheating taking place when temperatures of more than 25°C are recorded for more than 5% of occupied hours or temperatures of more than 28°C are recorded for more than 1% of occupied hours (CIBSE, 2015). Humphries (1979, as cited in CIBSE, 2015) showed that occupants experienced thermal discomfort at temperatures above 26°C. On the other hand, the *CIBSE TM52* recommends that the hours of exceedance (when the difference between the maximum acceptable temperature and the operative temperature equals or exceeds one degree (K)) for the period 1 May – 30 September to not be more than 3% of occupied hours (CIBSE, 2013), the daily weighted exceedance to be lower or equal to 6, and the difference between the maximum acceptable temperature and the operative temperature to not exceed 4K (CIBSE, 2013). BSEN 15251:2007 provides as benchmark for Category II buildings bedrooms overheating 26°C for sedentary ~1.2met level of activity and ~0.5clo, a PPD<10 and PMV between -0.5 and +0.5. *CIBSE TM36* and Hacker et al. (2005) established three thresholds for bedrooms: one of 'warm' for 21°C, one of "hot" for 25°C, with overheating if it takes place for more than 1% occupied hours, and 'heat distress' considered as harming health for 35°C at any time. This paper uses the *CIBSE TM36* criterion, considering also the PPD and PMV limits as per BSEN 15251:2007. This criterion, used also in other studies (Gupta et al., 2012), encompasses the limits set by *CIBSE Guide A*, but with a larger range to cover wider and more extreme overheating risk cases as London is highly impacted by the urban heat island (UHI) effect (Smith&Levermore, 2008; Taylor et al., 2015).

### ***Causes and Effects of Overheating***

The building related factors that cause overheating are high levels of airtightness, insulation (Jenkins et al., 2013), bad design, poor management (CIBSE, 2013). The contextual factors are external (climate change and UHI, urban morphology and greening (Mavrogianni et al., 2012)), and internal (users' behaviour and appliances). Similarly, *CIBSE KS16* (2010) includes: external (solar radiation on walls and windows, heat transmission through the fabric (walls, windows, roof), and through openings), and internal gains (equipment, lights, people).

### ***Retrofitting***

Overheating impacts on humans' health and increases energy consumption through cooling (Porritt et al., 2011; Mavrogianni et al., 2012; Bezaee et al., 2013), which contravenes to the UK's commitments (1998 Kyoto Protocol, 2010 Energy Performance of Buildings Directive, 2012 Energy Efficiency Directive and 2008 Climate Change Act). By 2050 75% of the existing



housing stock will still be standing (SDC, 2006). The dwellings built pre-1919, including Victorian houses, represent approximately 20% of the total stock (DCLG, 2015). Thus, a cheaper solution is to retrofit by applying design strategies to low carbon standards (Ji et al., 2014) to prevent overheating and align them with the new buildings' requirements. The risk of overheating can be reduced by choosing optimal retrofit measures (DECC, 2014): installation of shading devices (for east/west/south facing windows), increased insulation and airtightness. Windows, a major source of heat, need to be considered first (CIBSE, 2010). The solar gain through glazing is impacted by: orientation, glazed area and its characteristics, internal/external shading devices, the use of multiple glazing (BSI, 2005). To minimize the energy use, Goia (2016) recommends 0.30-0.45 optimum window-to-wall ratio. Insulation standards for external walls for the existing housing are internal, external or cavity filling (CIBSE, 2003), only internal and external for solid walls. The internal insulation is "the most cost-effective option", but with a loss of internal space and risk of thermal bridges. The recommended wall U-value is 0.45 W/m<sup>2</sup>K or better, with minimum insulation thickness 35-70 mm. The external insulation is the most expensive option, but with advantages such as combating dampness and avoiding thermal bridges. The ideal U-value is 0.35 W/m<sup>2</sup>K or better, and minimum insulation thickness 48-95mm (CIBSE, 2003; Weeks et al., 2013).

## Methodology

With climate change increasing the overheating risk, the research question is: what are the most efficient retrofitting solutions for a London Victorian house to prevent overheating and make it adapted to future climate change, whilst complying with the government's committed CO<sub>2</sub> reduction targets? This paper aims to investigate passive solutions targeting the mechanisms that cause heat gaining in a building: windows and external walls (TRCCG, 2008) to identify retrofitting solutions for a typical Victorian house to counteract the effects of the future predicted heat waves, so that its environmental impact to be also minimized.

### Victorian houses characteristics

The house is a mid-terrace house in East London, facing high street, 21° from north south-west/north-east orientation, and covers ground floor and two upper floors. The 1890s and 1910s historical maps placed the construction of the house within this period, including it in the pre-1919 solid wall houses category. Its main characteristics are described in Table 1.

Table 1 – Characteristics of the case study Victorian house

Traits	Description
Wall structure	Solid brick walls (no cavity)
	The thickness of the walls suggests the double Flemish bond for external walls, Flemish bond for inter-dwelling partitions, and one-brick layer for internal walls.
	Victorian house solid wall brick of 110x230x70mm, with a 10mm mortar layer.
Use	Mixed residential (shared house) and commercial
Internal structure	Real estate agent and a studio flat (family with child) on the ground floor, and four rooms rent to individuals on the first and second floors of the house (Fig.1).
Occupancy profiles	1. Pattern of 18:00-08:00 during the week and 24 hours during the weekend, respectively outside office hours, the time when the full-time employed occupants of the bedrooms of interest are home 2. A 24-hour pattern for children, old and vulnerable people who spend more time indoor
House environment	As a shared house, leaving the doors open for ventilation is not an option, therefore the house relies on natural ventilation by opening windows for cooling and on mechanical means for heating. It has poor airtightness (high air infiltration) and no insulation. The kitchen and bathroom are cooler in the summer, but the south-west bedrooms can get very hot, impacting on the users' comfort and wellbeing.

The occupancy profiles were chosen outside office hours as the occupants of the two bedrooms investigated are full-time employees, with 09:00-17:00 working hours. The shared house has no living-room, and inhabitants, unlike in a family house, spend most of

their time at home in the bedroom. Therefore, their occupied hours cannot be reduced to only 22:00-07:00, as in other studies (Porritt et al., 2011) and CIBSE (2017). The 24-hour occupancy profile aims at the most vulnerable categories (children, old people and people with health issues), the most prone to be affected by more frequent and longer heatwaves.



Figure 1. Case study house simulation model and floor plans (IES and Revit)

### Research Method

Computer simulation is used to investigate potential solutions to overheating over the summer, 1 May–30 September, the period focused on by CIBSE TM59 and CIBSE TM52, as the period with the highest temperatures during a year, and outside the October–April heating period (CIBSE, 2017). A dynamic model is created, at one-hour time intervals, in IES ModelIT, also used in similar studies (Gupta et al., 2012; Porritt et al., 2011; Jenkins et al., 2013), due to its user-friendly interface and reliable outputs. The resulting data was then manipulated in Excel. The north and south inter-dwelling partitioning walls are considered adiabatic to isolate the case study house from the influence of the adjacent houses' internal environment. As in other related research (Gupta et al., 2012), the future weather files used are Prometheus (University of Exeter) based on UKCP09, at London Islington meteorological station. They include current control 1970s files (based on the 1961–1990 period) and future predicted weather conditions for 2030s, 2050s and 2080s, considered the “extreme” climate change model (Gupta et al., 2012). For overheating assessment they contain Design Summer Year (DSY) files, with different degrees of uncertainty. The DSY 1970s files are used as control files, and the 2030s, 2050s and 2080s for medium and high emissions, to compare

between the corresponding risks, for 50 and 90 percentile, as representative for a lower degree of uncertainty, unlike the Gupta et al. (2012) study that considered only extreme scenarios (high emissions and 90 percentile probability). A comparison between the most optimistic (2030s medium 50 percentiles) and pessimistic weather files (2080 high 90 percentiles) show increases of 4-13.5°C in the outdoor temperatures, compared to 1970s.

### **Current state of the case study building and scenarios description**

The current rooms characteristics are as per Table 2 for walls and Table 3 for windows. They reflect the IES assigned materials and similar methods are used for all scenarios. The internal floor/ceiling's U-value is 1.048 W/m<sup>2</sup>K and the door's is 2.166 W/m<sup>2</sup>K.

Table 2. Current house specifications for walls (IES software)

Element	Material	Thickness (mm)	Conductivity (W/m K)	Density (Kg/m <sup>3</sup> )	Specific Heat Capac. (J/kgK)	Resistance (m <sup>2</sup> K/W)	Vapour resist. (GNs/kg m)	U-val. (W/m <sup>2</sup> K)	Total R-val. (m <sup>2</sup> K/W)	Total thickness (mm)	Therm mass (KJ/m <sup>2</sup> K)
External Wall	Brick	350	0.84	1700	800	0.015	58	1.503	0.488	365	126.1
	Plasterboard	15	0.21	400	1000	0.060	0				
Internal Partition	Plasterboard	15	0.21	700	1000	0.060	0	1.803	0.320	140	85.3
	Brick	110	0.62	1700	800	0.081	35				
	Plasterboard	15	0.21	700	1000	0.060	0				

Table 3. Current house specifications for windows double-glazing (IES software)

Material	Thickness	Width (m)	Height (m)	Area (m <sup>2</sup> )	Conductiv. (W/m K)	Gas	Resistance (m <sup>2</sup> K/W)	Net U-value (+ frame) (W/m <sup>2</sup> K)	U-value (glass only) (W/m <sup>2</sup> K)
Outer Pane	4.00	1.30	2.00	2.60	1.06	-	0.00	1.44	1.09
Cavity	16.00				-	Argon	0.73		
Inner Pane	4.00				1.06	-	0.00		

Individual and clustered scenarios (S1-S9 in Table 4), focused on windows and walls, are compared against the 1970s baseline and between each other, for the mentioned period. The total number of hours is 3672 hours for the 24-hour occupancy, and 2596 hours for the 6:00pm-8am Monday-Friday and full weekend occupancy. The threshold temperatures used are 25°C for “hot” or for overheating when more than 1% of time, and for 35°C at any time (CIBSE, 2005; Hacker et al., 2005), for comfort zones by also taking into consideration PPD (less than 10) and PMV (between -0.5 and +0.5) (BS EN 15251:2007). Bedroom 2 is on the first floor facing south-west, and Bedroom 3 on the second floor, above Bedroom 2. IES room conditions: heating: “on continuously” with heating setpoint 18°C, cooling is “off continuously”. Internal gains: fluorescent lighting and people. Air exchange: infiltration, with maxim flow of 0.25ach. Other comfort parameters: TM52 Adaptive Comfort, Category II of building, air speed 0.15m/s, activity level “seated at rest”, and 0.5 clothing. The internal and external insulation is 95 mm expanded polystyrene (CIBSE, 2013).

Table 4. Scenarios investigated

Single solutions	S1	External insulation	Thickness is 95mm (CIBSE, 2003 - for refurbishment for existing houses), the maximum of the 48-95mm insulation thickness range to achieve U-value of 0.35 W/m <sup>2</sup> K or better. U-value of the resulting wall: 0.29W/m <sup>2</sup> K.
	S2	Internal insulation	Same type and thickness insulation, but applied on the internal side of the wall. All the other characteristics remain as original. U-value of the new wall: 0.29W/m <sup>2</sup> K.
	S3	Triple-glazing replaces double-glazing	The characteristics and properties of the triple glazing are as above. All the other characteristics remain as per the original model. U-value is 0.89W/m <sup>2</sup> K.
	S4	Windows area reduction by 50%	All the other characteristics remain but the windows are reduced 50%, by halving them on their length from the top, so that their height now is 1m, and width 1.3m. The windows will remain in the same position.
Combined solutions	S5	External insulation + triple glazing	
	S6	Internal insulation + triple glazing	
	S7	External insulation + windows area reduction by 50%	
	S8	Internal insulation + windows area reduction by 50%	
	S9	Triple glazing + windows area reduction by 50%	

## Results of the scenarios investigation

The results of the simulation, exemplified in Table 5, reveal as the best scenario the one of a combination of glazing manipulation: 50% windows reduction and triple-glazing replacing double-glazing, followed by the scenario of 50% windows reduction. The worst one refers to the use of internal insulation, followed by the internal insulation with triple-glazing.

Table 5 – The results of the simulation, with the best and worst strategy, for some of the weather scenarios

Weather file	Investigated scenarios	Temperature Bedroom 2 (B2) (°C)	B2 vs. B3	Temperature Bedroom 3 (B3) (°C)	Overheating risk temperatures		Solutions value in relation with others
					>25°C(overheat,for>1 % occupied hours)	>35°C (heat distress)	
Current 1970s	S9 (S3 + S4)	27.5	>	27.4	Yes	No	Best
	S4	27.8	>	27.6	Yes	No	Second best
	S2	35.2	<	35.4	Yes	Yes	Worst
	S6 (S2 + S3)	34.8	<	35.1	Yes	No/ Yes	Second worst
	S1	34.5	<	34.6	Yes	No	Third worst
2030s medium 50 percentile	S9 (S3 + S4)	31.7	>	31.5	Yes	No	Best
	S4	32	>	31.8	Yes	No	Second best
	S2	39.4	<	39.5	Yes	Yes	Worst
	S6 (S2 + S3)	39	<	39.1	Yes	Yes	Second worst
	S1	34.5	<	34.6	Yes	No	Third worst
2050 high 50 percentile	S9 (S3 + S4)	32.8	>	32.6	Yes	No	Best
	S4	33.1	>	32.9	Yes	No	Second best
	S2	39.8	<	39.9	Yes	Yes	Worst
	S6 (S2 + S3)	39.3	<	39.5	Yes	Yes	Second worst
	S1	38.8	<	38.9	Yes	Yes	Third worst
2080s high 90 percentile	S9 (S3 + S4)	40.6	>	40.5	Yes	Yes	Best
	S4	43.89	>	43.87	Yes	Yes	Second best
	S2	49.2	<	49.4	Yes	Yes	Worst
	S6 (S2 + S3)	48.8	<	49	Yes	Yes	Second worst
	S1	48.5	<	48.7	Yes	Yes	Third worst

The percentages for the occupancy profiles are close to each other, their values almost overlapping (Fig.2 and 3). Thus, the percentages of the times with high temperatures is the same for the total occupancy times, but the differences reside in a prolonged time exposed to high temperatures for the 24-hour profile. The temperature level patterns for both Bedrooms follow the same trend on the scenarios investigated and for both occupancy profiles, similar for the number of hours above 25°C and 35°C (Fig.4 and 5).

## Discussion of the results

Based on the initial criteria considered for assessing overheating risk, 25°C for more than 1% occupied hours threshold, or 35°C any time (CIBSE, 2005; Hacker et al., 2005), and PPD comfort zones smaller than 10 and PMV between -0.5 and +0.5 (BS EN 15251:2007), this research found that the optimal strategy would be to reduce the windows area, or combine this solution with the one of triple-glazing for windows, with the temperatures below 35°C for most of the scenarios investigated, but still over this threshold for the most extreme future predicted weather scenarios, when the temperatures reach 40°C, almost 10°C above the current conditions values.

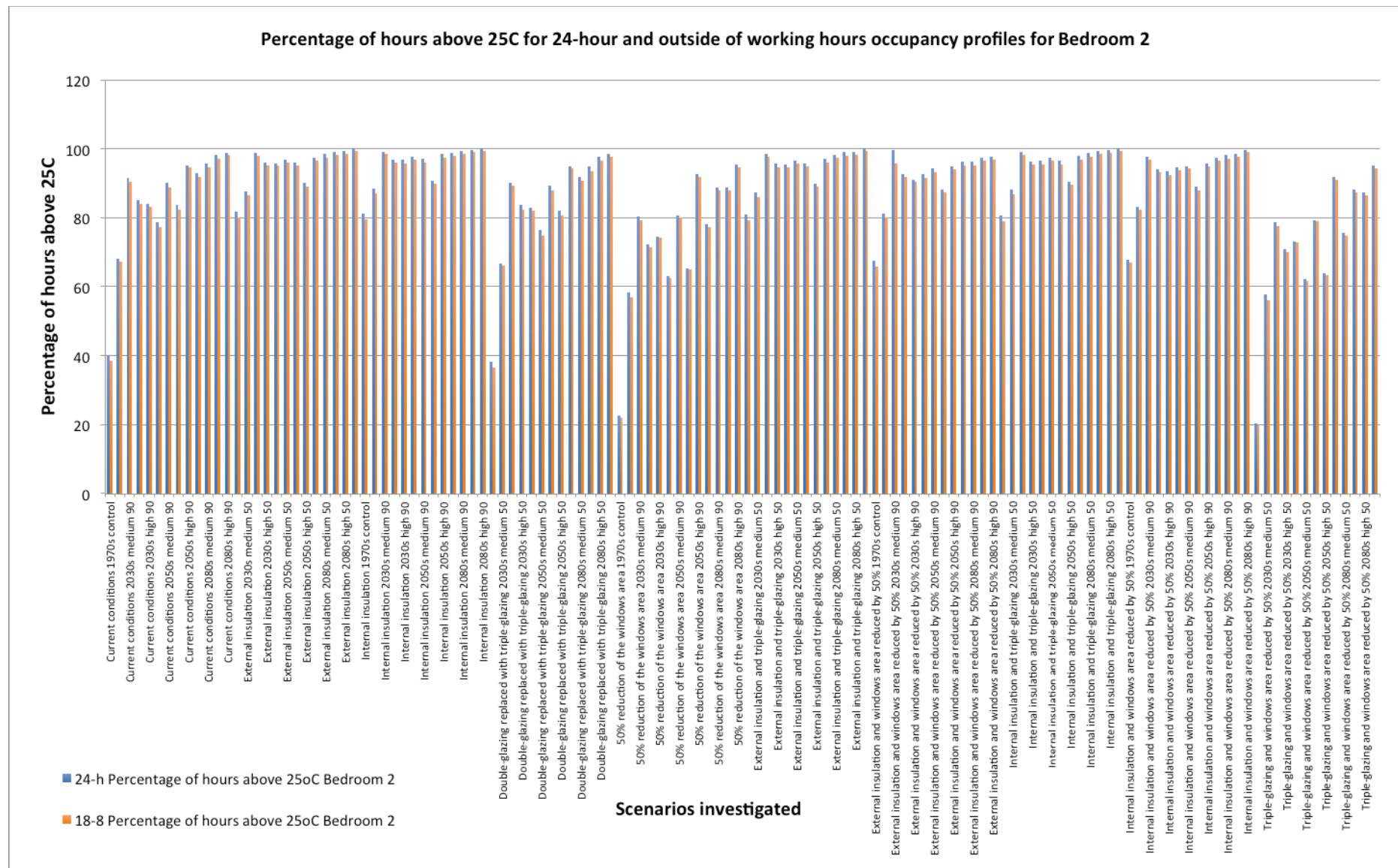


Figure 2. Percentage of hours above 25°C for 24-hour and 18:00-08:00 occupancy profiles for Bedroom 2 (IES and Excel)



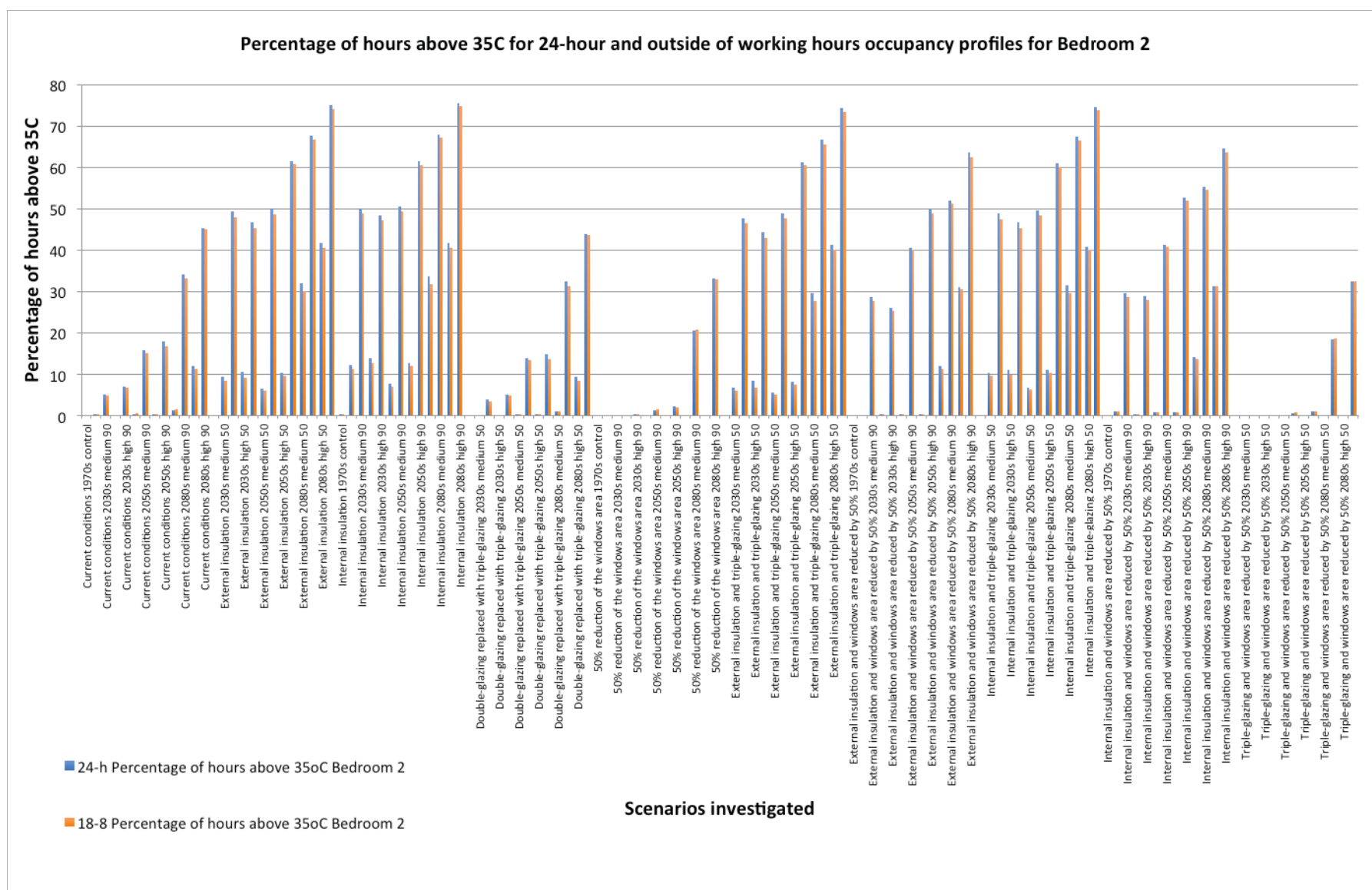


Figure 3. Percentage of hours above 35°C for 24-hour and outside of working hours occupancy profiles for Bedroom 2 (IES and Excel)



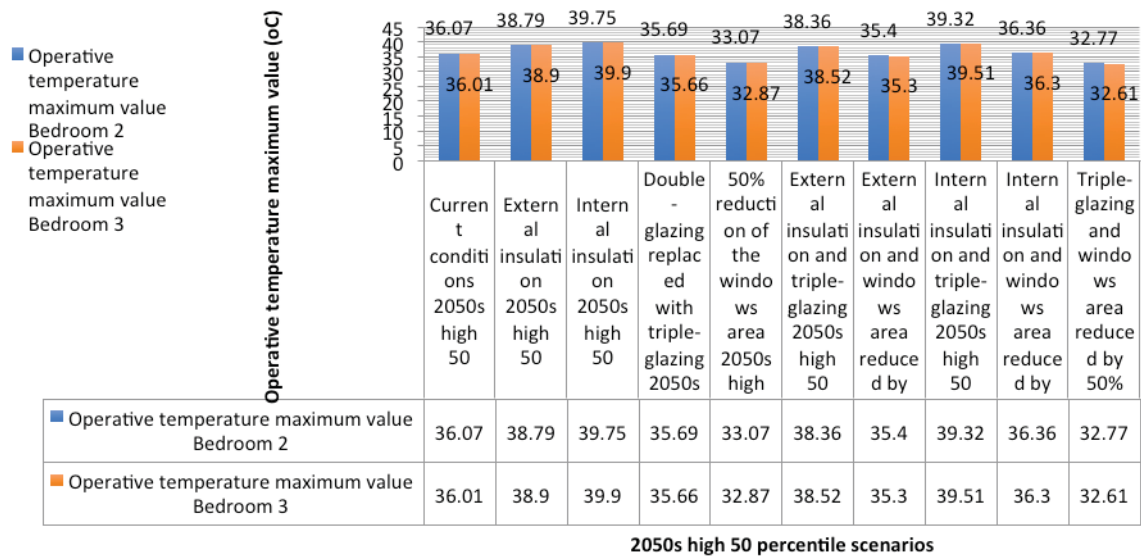


Figure 4. Maximum operative temperature values for the 2050s high 50 percentile weather file (Excel)

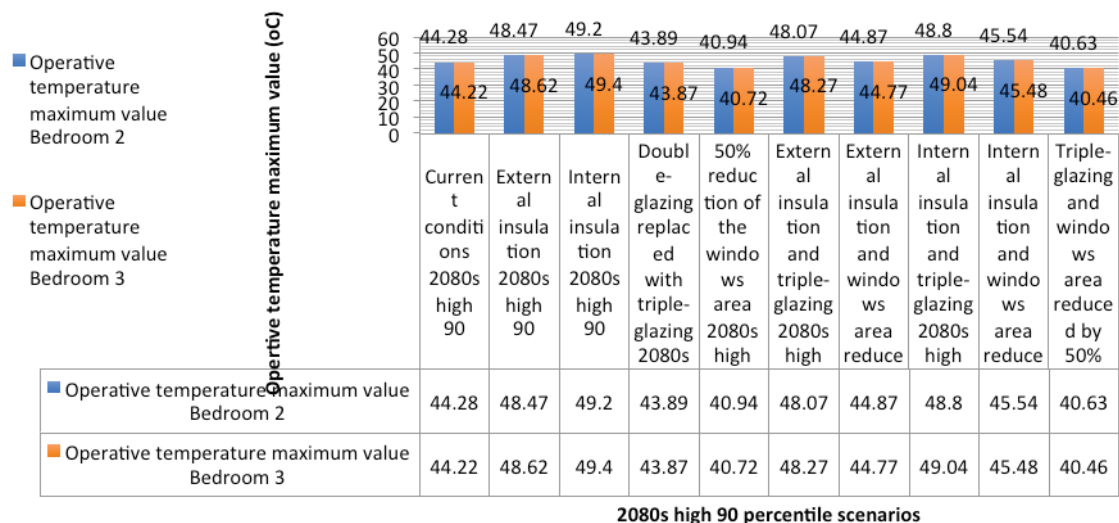


Figure 5. Maximum operative temperature values for the 2080s high 90 percentile weather file (Excel)

Both internal and external insulation contribute to the increase of overheating, as the new temperatures are higher than the ones for the current, confirming Porritt et al. (2012) research. Another common ground is that Porritt et al. (2011) and Mavrogianni (2012) also found that internal insulation is less effective than the external one increasing the number of degree hours with 14%. This paper shows a difference of around 1°C between the two and a higher number of hours of overheating. Solar gain control through glazing has a higher importance for overheating risk than the fabric related ones (insulation). The reduction of the window area was more significant than changing the glazing type from double-glazing into triple-glazing. In addition, Porritt et al. (2012) investigated other glazing related strategies such as low-e double glazing. Porritt et al. (2012) consider that users and their occupancy profiles have a significant role in assessing the suitable strategies for preventing overheating risk in buildings. This paper acknowledges the difference as the amount of time each type of participant is exposed to overheating, but it also reveals that the percentages of time are similar for the two situations as per the total amount of time. Yet, the 24-hour residents are more affected by the overheating than the outside office hours profile

residents due to the different exposure times in a day. Between the two floors there is a slight difference with generally higher temperatures on the first floor. No research has been found on such result. The assumption is that a higher height difference might mean a higher difference in the indoor temperature, but it does not necessarily mean a difference in the same direction. Also, there might be other factors that influence the indoor temperature, apart from the height, factors that were not taken into consideration within this study.

## Conclusions

The results show that glazing manipulation is the optimum way to avoid overheating. This study validates the results Porritt et al. (2011) and Porritt et al. (2012) reached regarding the external wall insulation being more efficient than the internal one. The weather files used and the occupants' behaviour proved paramount in the outcome of the overheating assessment (CIBSE, 2017). Limitations of this paper refer to the omitting to investigate strategies that impact on the levels of heating and thermal comfort in winter, as beyond the scope of this paper, and also to the use of IES and the accuracy of the input data, in addition to the predictive nature of the weather files used. Currently more research is conducted to refine the future climate scenarios through UKCP18 (drawn on UKC09). The growing interest in this topic is materialised by the development of CIBSE TM59 to standardise overheating risk assessment methods. Further research is recommended to test strategies such as different types of insulation and different thicknesses, but also other combined solutions.

## References

- Beizaee, A., Lomas, K. J. and Firth, S.K. (2013). National survey of summertime temperatures and overheating risk in English homes. *Building and Environment*, 65, pp.1-17.
- BSI (2005) BS EN ISO 7730:2005 *Ergonomics of the thermal environment – Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria*. London: British Standards Institution.
- BSI (2007) BS EN 15251:2007 *Indoor Environmental Input Parameters for Design and Assessment of Energy Performance of Buildings Addressing Indoor Air Quality, Thermal Environment, Lighting and Acoustics*. London: British Standards Institution.
- CIBSE (2005) *Climate change and the indoor environment: impacts and adaptation. Technical Memoranda TM36*, London: Chartered Institution of Building Services Engineers.
- CIBSE (2010) *How to manage overheating in buildings. A practical guide to improving summertime comfort in buildings*, CIBSE Knowledge Series: KS16. London: Chartered Institution of Building Services.
- CIBSE (2013) *Limits of Thermal Comfort: Avoiding Overheating in European Buildings. Technical Memoranda TM 52*. London: Chartered Institution of Building Services Engineers.
- CIBSE (2015) *Environmental Design - Guide A', 8th edition (issue 2) (incorporates corrections – September 2105 and January 2016). Guide A*. London: Chartered Institution of Building Services Engineers.
- CIBSE (2017) *TM59: Design methodology for the assessment of overheating risk in homes*, London: The Chartered Institution of Building Services Engineers.
- Cramer, M.N. and Jay, O. (2016). Biophysical aspects of human thermoregulation during heat stress. *Autonomic Neuroscience: Basic and Clinical*, 196, pp.3-13.
- Crump, D. (2011) *Climate change – health impacts due to changes in the indoor environment; Research needs*, Cranfield: Institute of Environment and Health. Available at: [https://dspace.lib.cranfield.ac.uk/bitstream/1826/7001/1/climatechange\\_reportieh\\_feb-2011.pdf](https://dspace.lib.cranfield.ac.uk/bitstream/1826/7001/1/climatechange_reportieh_feb-2011.pdf) (Accessed: 6 February 2016).
- DEFRA (2009) *Adapting to climate change. UK climate projections*, Department for Environment, Food and rural affairs. Available at: [https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/69257/pb13274-uk-climate-projections-090617.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69257/pb13274-uk-climate-projections-090617.pdf) (Accessed 22 March 2016).
- Department of Energy & Climate Change (DECC) (2014) *Guidance on preventing overheating in the home*, Available at <http://www.cibse.org/getmedia/4a1e86ee-ea51-44ba-95fb-54f3165282cf/DECC-Overheating-guidance-document-19Jun2015.pdf.aspx> (Accessed 5 May 2016).

Department for Communities and Local Government (DCLG) (2015) *English housing survey: headline report 2013-2014*. Available at: [https://www.gov.uk/government/uploads/system/uploads/attachment\\_data/file/406740/English\\_Housing\\_Survey\\_Headline\\_Report\\_2013-14.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/406740/English_Housing_Survey_Headline_Report_2013-14.pdf) (Accessed: 28 May 2015).

Goia, F. (2016). Search for the optimal window-to-wall ration in office buildings in different European climates and the implications on total energy saving potential. *Solar Energy*, 132, pp.467-492.

Gupta, R. and Gregg, M. (2012). Using UK climate change projections to adapt existing English homes for a warming climate. *Building and Environment*, 55, pp.20-42.

Hacker, J.N., Belcher, S.E. and Connell, R.K. (2005) *Beating the heat: keeping UK buildings cool in a warming climate*. UKCIP Briefing Report. UKCIP, Oxford. Available at: [http://www.ukcip.org.uk/wordpress/wp-content/PDFs/Beating\\_heat.pdf](http://www.ukcip.org.uk/wordpress/wp-content/PDFs/Beating_heat.pdf) (Accessed: 15 May 2016).

IPCC (2014) *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland. Available: <http://www.ipcc.ch/report/ar5/syr/>. (Accessed: 5 March 2016)).

Jenkins, D.P., Ingram, V., Simpson, S.A., Patidar, S. (2013). Methods for assessing domestic overheating for future building regulation compliance. *Energy Policy*, 56, pp.684-692.

Ji, Y., Fitton, R., Swan, W., Webster, P. (2014). Assessing overheating of the UK existing dwellings – A case study of replica Victorian end terrace house. *Building and Environment*, 77, pp.1-11.

Jones, G.S., Stott, A.P., Christidis, N. (2008) 'Human Contribution to rapidly increasing frequency of very warm Northern Hemisphere summers', *Journal of Geophysical Research*, 113. Available at: <http://onlinelibrary.wiley.com/doi/10.1029/2007JD008914/full> (Accessed: 15 May 2016).

Mavrogianni, A., Wilkinson, P., Davies, M., Biddulph, P. and Oikonomou, E. (2012). Building characteristics as determinants of propensity to high indoor summer temperatures in London dwellings. *Building and Environment*, 55, pp.117-130.

Murphy, J., Sexton, D., Jenkins, G., Boorman, P., Booth, B., Brown, K., Clark, R., Collins, M., Harris, G., Kendon, L. (2009). *UK climate change projections science report: climate change projections, technical report*. Exeter: Meteorological Office Hadley Centre. Available: <http://scdc.onesuffolk.net/assets/Documents/LDF/B7F/UKCP09ProjectionsV2.pdf> (Accessed: 5 May 2016).

Nicol, F., Humphreys, M. and Roaf, S. (2012) *Adaptive thermal comfort: principles and practice*, Abingdon and New York: Routledge.

Oraiopoulos, A., Kane, T., Firth, S.K., Lomas, K.J. (2015). Measured internal temperatures in UK homes – A time series analysis and modelling approach. *Energy Procedia*, 78, pp.2844-2850.

Oseland, N.A. (1995). Predicted and reported thermal sensation in climate chambers, offices and homes. *Energy and Buildings*, 23, pp.105-115.

Porritt, S., Shao, L., Cropper, P., Goodier, C. (2011). Adapting dwellings for heat waves. *Sustainable Cities and Society*, 1, pp.18-90.

Porritt, S.M., Cropper, P.C., Shao, L., Goodier, C.I. (2012). Ranking of interventions to reduce dwelling overheating during heat waves. *Energy and Buildings*, 55, pp.16-27.

Rodrigues, L.T., Gillott, M., Tetlow, D. (2013). Summer overheating potential in a low-energy steel frame house in future climate scenarios. *Sustainable Cities and Society*, 7, pp.1-15.

Schweizer, C., Edwards, R.D., Bayer-Oglesby, L., Gauderman, W.J., Ilacqua, V., Jantunen, M.J., Lai, H.K., Nieuwenhuijsen, M. and Künzli, N. (2007) 'Indoor time – microenvironment – activity patterns in seven regions of Europe', *Journal of Exposure Science and Environmental Epidemiology*, 17, pp.170-181. Available: <http://www.nature.com/jes/journal/v17/n2/pdf/7500490a.pdf>. (Accessed: 5 May 2016)

Smith, C. and Levermore, G. (2008). Designing urban spaces and buildings to improve sustainability and quality of life in a warmer world. *Energy Policy*, 36, pp.4558-4562.

Smith P.F. (2007) *Sustainability at the cutting edge. Emerging technologies for low energy buildings*, 2<sup>nd</sup> edn, Oxford: Architectural Press.

Sustainability Development Commission (SDC) (2006) *Stock take*. Available: [http://www.sd-commission.org.uk/data/files/publications/Stock\\_Take.pdf](http://www.sd-commission.org.uk/data/files/publications/Stock_Take.pdf) (Accessed: 28 May 2015).

Taylor, J., Wilkinson, P., Davies, M., Armstrong, B., Chalabi, Z., Mavrogianni, A., Symonds, P., Oikonomou, E., Bohnenstengel, S.I. (2015). Mapping the effects of urban heat island, housing and age on excess heat-related mortality in London. *Urban Climate*, 14, pp.517-528.

Three Regions Climate Change Group (TRCCG) (2008) *Your home in a changing climate. Retrofitting existing homes for climate change impacts*. Available <http://climatelondon.org.uk/wp-content/uploads/2012/10/Your-home-in-a-changing-climate.pdf>, (Accessed 28 May 2015).

Weeks, C., Ward, T. and King, C. (2013) *Reducing thermal bridging at junctions when designing and installing solid wall insulation*. Garston: IHS BRE Press.

## Development and implementation of a cloud-based IoT platform to monitor and maintain buildings efficiently using power quality data

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**Abstract:** Modern commercial buildings are designed and constructed with a BMS system and are linked to digital electric meters, but in most cases, these systems are not used to their full potential. The use of a digital electric meter can be enhanced by connection to the cloud, hence making an Internet-of-Things (IoT) device. The InnovateUK funded research 'Building Asset Risk Management' (BARM) focuses on the commercial implementation of such a device, to aid facility managers in operating and managing their buildings effectively and efficiently. The project has developed a cloud-based platform that extracts data from digital electric meters and then hosts this in the cloud. The cloud system uses state of the art web technology such as NoSQL and MQTT to manage the data. The installation of these monitoring systems is vital for the future of smart cities, where many devices will need to be connected to the electrical points - such as electric car recharging stations - greatly increasing buildings' power usage. In particular, greater power requirements can cause high Total Harmonic Distortion (THD), which reduces the efficiency of the electrical systems and can cause costly downtime. It can also result in nuisance tripping and short circuits leading to a fire. Reducing THD can increase mean time between failures of electrical assets; thus, this type of power quality data can significantly impact maintenance requirements, minimising critical downtimes in large buildings. The research shows how the monitoring of: THD, voltage, current and other variables to track breaker limits and identify trends in electrical power usage. This allows the facility managers to adopt predictive maintenance strategies. Three case studies are presented here which highlight the benefits of implementing such novel technology, mitigating areas of risk in commercial settings; and providing real scope for academic and industrial innovation in the smart cities initiative.

**Keywords:** Asset risk management, Power quality data, Smart building, Internet of Things (IoT), Software as a Service (SaaS)

## Introduction

New commercial buildings are installed with digital electric meters but these meters are not used to their full potential. The use of these meters can aid facility managers to manage their building more efficiently. According to AlFaris et al. (2017), two-thirds of the electrical energy is consumed by buildings globally, therefore it is vital to optimise the use of electrical energy to help reduce energy consumption and reduce carbon emissions. The increase in human population, economic growth and the development of new technological devices are increasing the demand for electricity (Van Vliet et al., 2016). The electrical appliances of the future will be able to communicate with each other and will also be connected to the internet, therefore it is very important to develop a platform that can enable electric meters to send data to the cloud using the internet – hence making it part of the Internet of things (IoT) (Ahmad et al., 2016). This will make commercial buildings smarter, allowing other IoT devices to communicate and be able to use data from the electric meters to develop intelligence. Subsequently, this would enable the whole building to function as one, increasing energy efficiency without compromising on the comfort of the occupants (Minoli et al., 2017).

As our lives become increasingly digitalised, the addition of electrical assets to existing energy systems will increase stresses, particularly in relation to their own physical limits (Nair and Jing, 2013) and would induce cumulative power quality effects – creating further stresses on the very assets being powered by the system; hence compromising their performance and associated life. The breaking of physical limits can cause potential business-critical building downtime and asset degradation issues such as fire risks, equipment lifetime reductions and nuisance tripping (Baggini and Hanzelka, 2008). Any assets that draw power also provide electrical power quality data signatures that can be used to enhance the building's overall life performance by pro-actively indicating the requirement for maintenance and/or possible near-failure (Birkner, 2017). These data points are available to extract from most, if not all, commercial/industrial meters but are rarely used in a systematic way.

The commercial Building Management System (BMS) is generally used to control heating and cooling systems installed in a building to reduce energy consumption and electricity is monitored to calculate the cost of power usage (Merabti et al., 2017). The potential to detect problems and identify asset risk is unexploited. Current platforms use a very small percentage of the available data from electrical meters, therefore underutilising the substantial capital investment of these meters and the associated BMS systems in commercial properties (Lee et al., 2013). Digital electric meters have the ability to capture a vast quantity of data that can be used to manage buildings more effectively. The data from these meters can influence energy saving by providing facility managers with in-depth knowledge of their power usage (Lee and Cheng, 2016). In a complex commercial building environment, electrical/mechanical equipment can fail unexpectedly due to insufficient intelligence provided by the existing platforms about the whole system performance. The examples of such failures are as follows: phase imbalances leading to the degradation of 3-phase equipment downstream, hence lowering expected lifetime of the asset; excessive Total Harmonic Distortion (THD) that can exacerbate fire risk by causing overheating of power cables; and poor awareness of power consumption in relation to energy systems physical limits that can cause nuisance tripping (Popa et al., 2017).



## **Building Asset Risk Management (BARM)**

The data from commercial/industrial electrical meters can provide data signatures that indicate the requirement for maintenance and highlight possible asset near-failure times through the creation of harmonic signals. These signals can be easily collected by the meters but are rarely accessed or used to make informative decisions regarding asset management (Morales-Velazquez et al., 2017). Therefore, it is critical to develop and implement a cloud-based platform that would automate collection, processing and interrogation of the relevant data for a commercial building setting and thus drive actions to extend the performance and lifetime of a building's energy system. This would help reduce the overall operational costs and lifetime capital costs through electrical, data-led, asset risk management (Sinopoli, 2016).

### **Type of computer clouds**

There are many different types of clouds such as: Software as a Service (SaaS), Infrastructure as a Service (IaaS) and Platform as a Service (PaaS). The SaaS cloud provides the end user with access to web-based software applications hosted on a server over the internet (Khalid et al. 2017). IaaS provides the end users with a software which they can control and maintain over the internet, giving them physical computing power (Jamsa 2013); and lastly PaaS provides users with a development environment in the cloud (Khalid et al., 2017), whereby developers can test, run and deploy new applications with reduced costs and complexity (Chandramouli 2011).

In this research, SaaS cloud was the most appropriate service employed to provide an enhanced asset risk management and predictive maintenance platform called Building Asset Risk Management (BARM) created for building owners and facility managers. This platform is novel as it provides a cloud-based application (accessible remotely) that utilises power quality data signatures from electric meters to deliver real-time insights into electrical asset performance. BARM data will ultimately extend the performance and lifetime of a building's energy system.

### **Development of a cloud-based platform**

Commercial and municipal buildings continue to integrate new energy technologies within their fabric during and after construction, the implementation of a cloud-based platform has a significant real-world application to optimise the energy efficiency of buildings (Pan et al., 2015). This InnovateUK funded SaaS platform, developed by Argand Solutions Ltd., was designed to be used with existing electric meters, thus no additional capital spend is generally required with this technology. The platform collects data from the existing meters using Modbus protocol and then translates the data into JavaScript Object Notation (JSON) format for transmission over the Internet to the Message Queue Telemetry Transport (MQTT) server. It is translated into JSON format because it uses less characters to represent data as compared to XML format and it also allows the platform to directly send the data to Not only Structured Query Language (NoSQL) database without any further translation (Khalid et al., 2017). After this, the MQTT server feeds the data to the NoSQL database. The NoSQL database sends the data to a node.js webserver as can be seen in Figure 1. This allows the client to view the data in real-time and allows them to request historical data from the database via a web server if needed. This enables a smooth transition of data



between the current BMS by enhancing it to provide advance analysis of the power quality data.

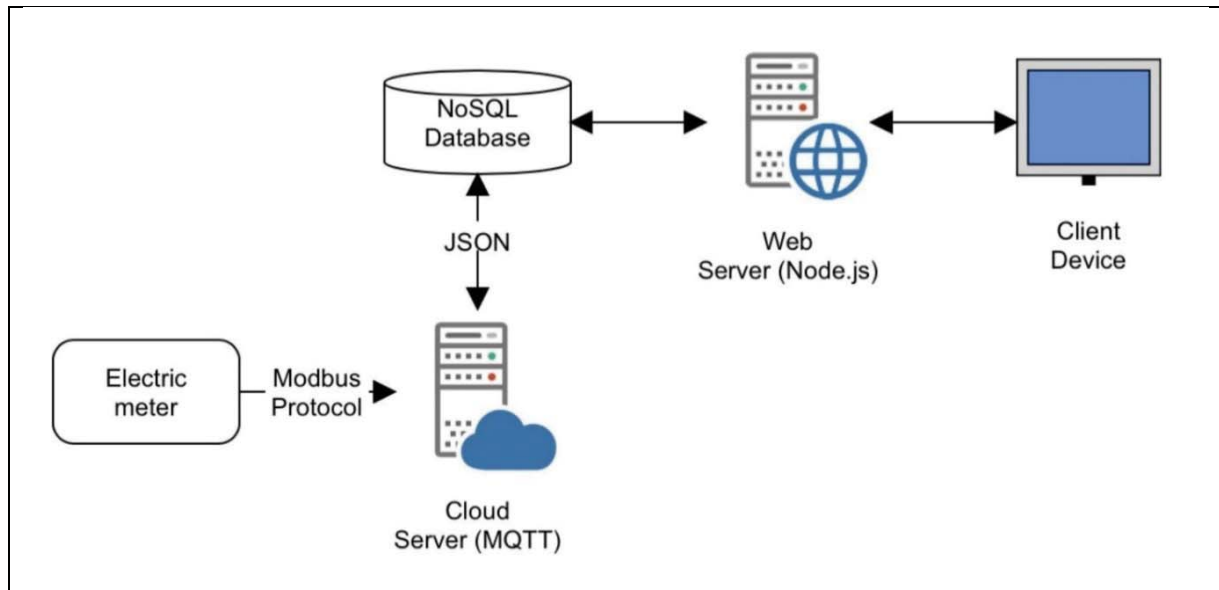


Figure 1: The implementation of cloud-based platform

The cloud-based application permits delivery of real-time insights into predictively assessing and valuing the risk of lifetime degradation of the building's equipment assets as well as the lifetime of the building's energy infrastructure. The platform iteratively analyses the electrical power quality data collected from the commercial electrical meters and converts it into usable, actionable and accountable actions within the context of a commercial building. The implementation of this platform provides the commercial sector with a cloud-based BARM platform at a small fraction of the reactive maintenance costs with no additional installation cost. It is known that predictive maintenance is more cost effective than reactive maintenance (Mobley, 2002). The power quality data can be directly extracted in real-time from the electric meters and then can be stored securely on the cloud for the facility managers to iteratively analyse and visualise the data in combination with a real-time messaging/traffic light information service for all the building's electrical assets/power circuits via a web interface. The solution, that this research project proposes, enables commercial and industrial property owners to respond pro-actively to actual energy system risk factors. This would lengthen the lifetime of both their buildings as a whole and the assets that use power (Jayamaha, 2016). The example of the developed dashboard can be seen in Figure 2.



Figure 2: Dashboard of the developed cloud-based platform

### Innovation and benefits of the implementation

The current building solutions are typically tailored to the simple management of Heating, Ventilation and Air Conditioning (HVAC) systems but fail to capture data from the electrical meters to optimise the energy consumption of the building (Al-Daraiseh et al., 2015). The developed platform mitigates the business-critical costs from equipment failing and creating a loss in productivity through significant downtime. It provides a solution that utilises the same hardware to offer additional benefits of cost savings through the provision of predictive maintenance and condition monitoring by leveraging the wider data sets available from these existing meters. The advantage of data being in the cloud is that building owners and facility managers can monitor their building from anywhere in the world as the data is stored and accessed via the internet (Truong and Dustdar, 2014).

This developed technology offers a new innovative solution by offering real-time analysis of electrical power quality data to the commercial facility managers and alerts them of any anomalies in the signal data in relation to their electrical assets. The platform enables them to detect asset degradation or early failure and improves the building energy efficiency through the interpretation of power quality data from electric meters. The implementation of this system provides the facility managers with energy asset data analytics to help resolve and provide feedback on any issues concerning monitored data over the project life cycle. BARM helps to calibrate and optimise the assets and maximise their useful life (Rondeau et al., 2017). The platform also interrogates the electrical power quality data from the meters to ensure that system limits have not been breached and that the assets are in a good condition, hence minimising the risk of unplanned outages due to system failures. It can be used effectively to ensure that large appliances installed in the building are supplied with the correct voltage and power factor as identified in the specification by providing in-depth analysis of the pre and post power quality data signatures at the site. It is essential that critical equipment installed in the building is supplied with the correct input power to increase both energy efficiency and life.

The cloud-based platform also provides a range of inter-related economic, environmental and social benefits. These include: a reduction in energy system maintenance costs; the development of real-time predictive maintenance that allows greater use of social

capital for more productive actions, as a result of minimising reactive maintenance work; and lowers embedded energy, which can assist building owners to apply for accreditation schemes such as BREEAM and LEED (Pan et al., 2015). The energy saving potential of the platform will thus also provide the owners with obvious additional economic gains.

### Meter data output for predictive maintenance

Electrical meters can output many different data variables, however the main variables of interest in this research project were: current, voltage, power factor, apparent power, frequency and harmonics on current and voltage. Summaries of the issues that can be detected by the variables are highlighted in **Error! Reference source not found.** and detailed below.

Table 1: Issues those can be detected by the variables extracted from the electrical meter

		Current	Voltage	Power Factor	Apparent Power	Frequency	Harmonics on Current	Harmonics on Voltage
1	Equipment failure	✓	✓				✓	✓
2	Equipment degradation	✓	✓	✓			✓	✓
3	Nuisance Tripping	✓	✓			✓	✓	✓
4	Fire risks	✓	✓	✓			✓	✓
5	Expansion limits	✓			✓			
6	Energy System limit	✓	✓		✓	✓	✓	✓
7	Utility contract limit			✓	✓			
8	Electrical efficiency			✓			✓	✓
	Disruption of sensitive equipment		✓			✓	✓	✓

1. Equipment Failure: Different data points can show signs of imminent failure and/or increasing the risk of failure through trend analysis. The Equipment failure is equal to business-critical risk (Li et al., 2017).
2. Equipment Degradation: Different data points can show signs of equipment degrading and/or higher risk of equipment degradation due to the electrical system setup. Mitigation can reduce capital spending costs through equipment maintenance/upgrades pre-failure (Mehta and Parekh, 2017).

3. Nuisance Tripping: As power quality data points move above certain levels it can increase the risk of nuisance tripping and should be actioned to investigate. The tripping can cause loss of business-critical energy supply (Escrivá-Escrivá et al., 2016).
4. Fire Risks: A range of power quality data points can indicate high or increasing electrical fire risk. This is especially true for harmonics on an electrical network.
5. Expansion Limit(s): Specific power quality data will indicate if the building energy system is approaching its physical maximum. This indicator means smarter growth planning to ensure that the existing energy system can support further commercial growth.
6. Energy Sub-System Limit(s): This power quality data will indicate that certain sub-energy system limits are approaching their maximums. The breaking of these sub-limits can cause business critical loss of energy supply to building and/or electrical assets.
7. Utility Contract Limit(s): Utility imposed limits will increase costs if broken. Power quality data can indicate when a system reaches that limit. The breaking of these limits can lead to punitive costs.
8. Electrical Efficiency: If the electrical efficiency of a building system can be improved it will enable better use of energy and reduction of wider energy system risks. Reduced efficiency means higher costs to business and lower asset lifetimes.
9. Disruption of Sensitive Equipment: A lot of electrical equipment requires electrical power to be delivered within specified tolerance levels. If limits are broken then the assets can fail hence causing critical business failure risks (Fuchs and Masoum, 2008).

## Project Case Studies

### Sports Dock Case Study

The BARM system was installed and tested at the University of East London, Sports Dock building, an innovative and highly complex site containing: public space, sports hall, gym, catering/refectory and office spaces within a high-performance building envelope. The building contains many of the power components that would normally be found in several different building types. The use of this site demonstrates that the developed cloud-based platform can be utilised within a multifaceted environment. The data analysed in this paper was collected over a 12 week period using the latest version of the BARM platform.

It is recommended that voltage imbalance should not be more than 2% (Shahnia and Ghosh, 2014) and in this case study, it was observed that the voltage imbalance during the 12 week period was under this critical limit (as seen in **Error! Reference source not found.**).

The voltage limit in the UK is 415V, with an uncertainty of -6% and +10% (Hall and Greeno, 2011). In the Sports Dock building, all meters were showing values over 440V (Figure 4). This research therefore highlighted a major voltage issue, with certain risk of equipment degradation and shortened MTBF.

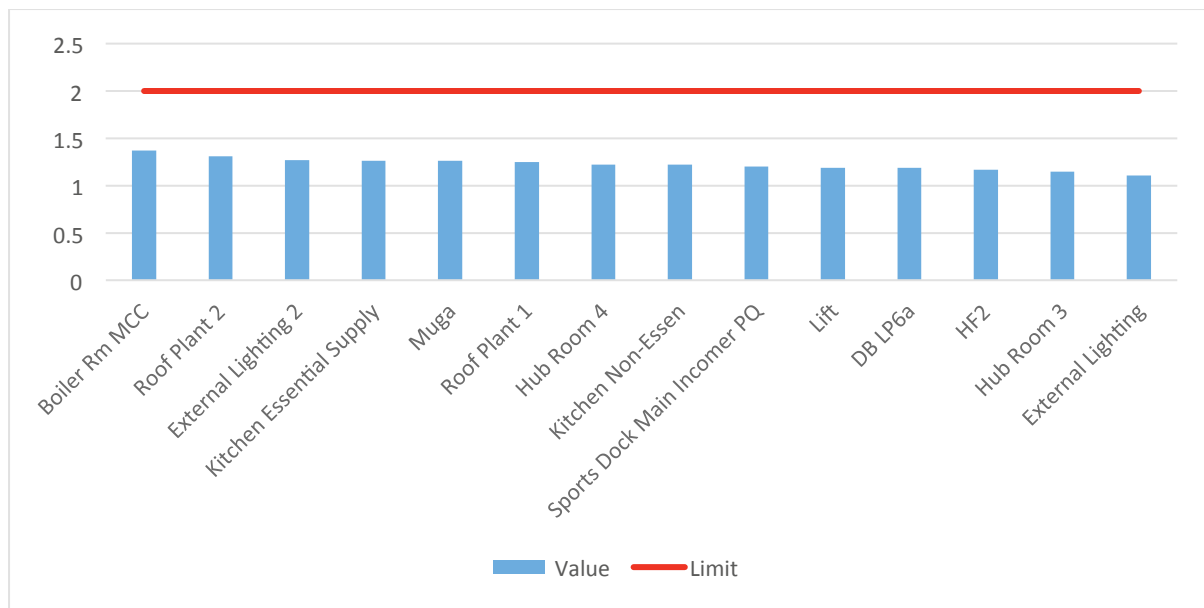


Figure 3: 3-Phase Voltage Imbalance of the meters

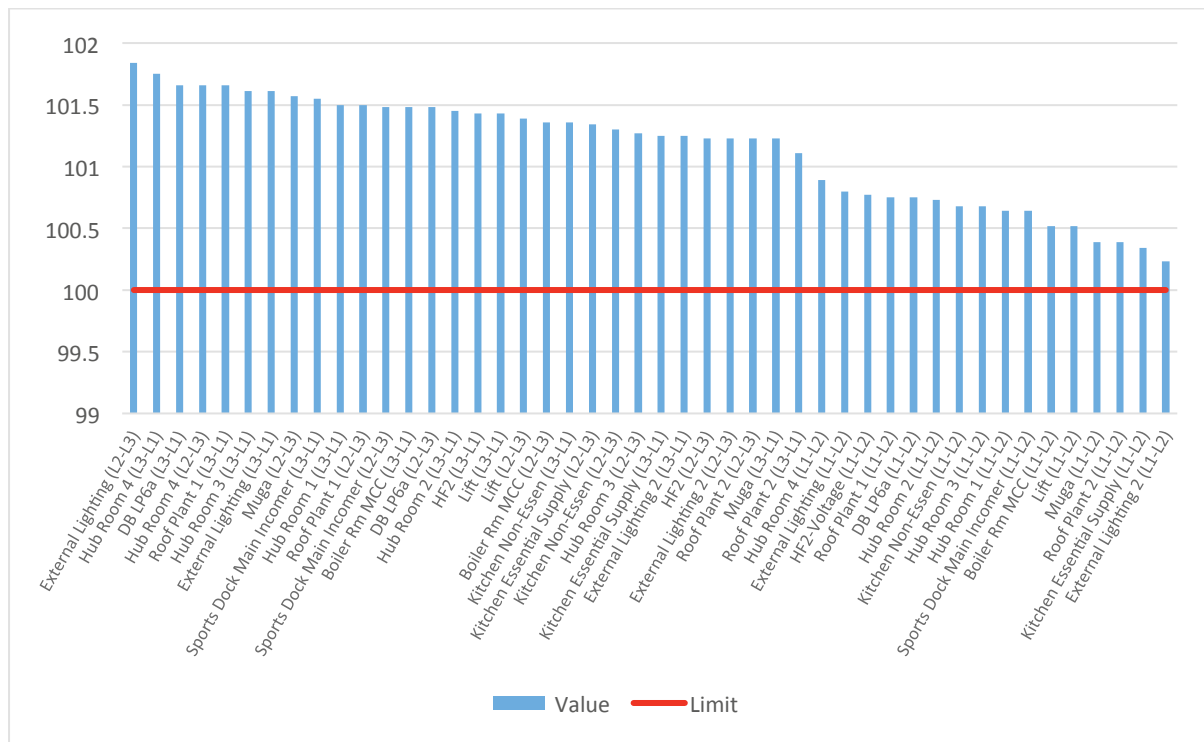


Figure 4: Maximum voltage levels of the meter as a percentage to 440 Volts

Figure 5 shows that six electrical meters were also above or at the critical limit of current imbalance. The critical limit of current imbalance is 10% (Heseltan, 2014). Therefore, the research was used to inform facility managers that this ought to be rectified immediately, by redistributing the load to balance the six electrical meters and bring them under the 10% limit.

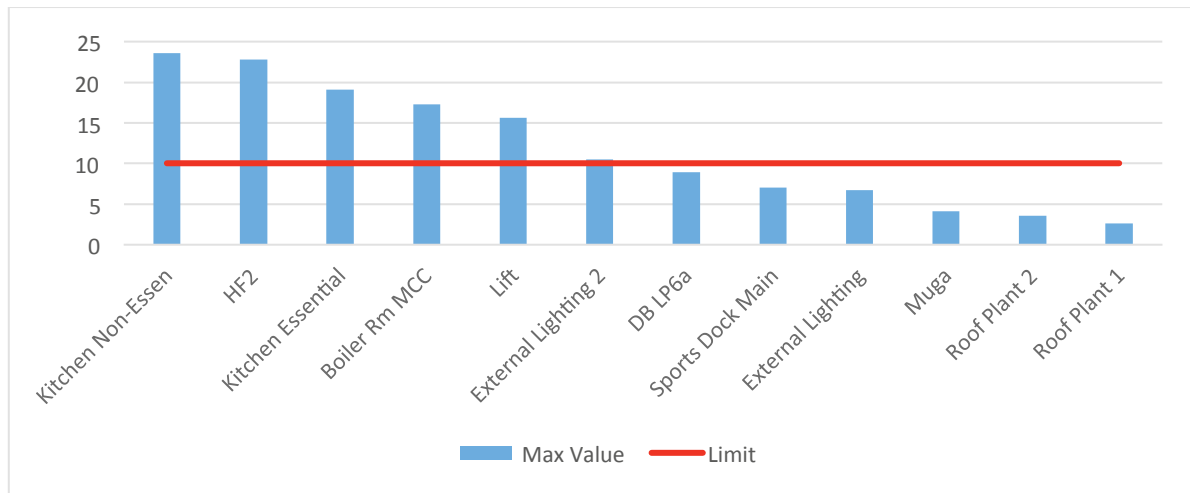


Figure 5: 3-Phase Current Imbalance

The Total Harmonic Distortion (THD) was analysed and it was observed that 83% of the THD on the network was generated by the plant installed on the roof. **Error! Reference source not found.** highlights this as meters for Roof Plant 1 and Roof Plant 2 – which are significantly worse than the next asset. THD current generated by the electrical system is important because high levels are known to cause a loss of electrical power (Santiago et al., 2017), resulting in costly equipment failures and degradation of asset components reducing lifespan.

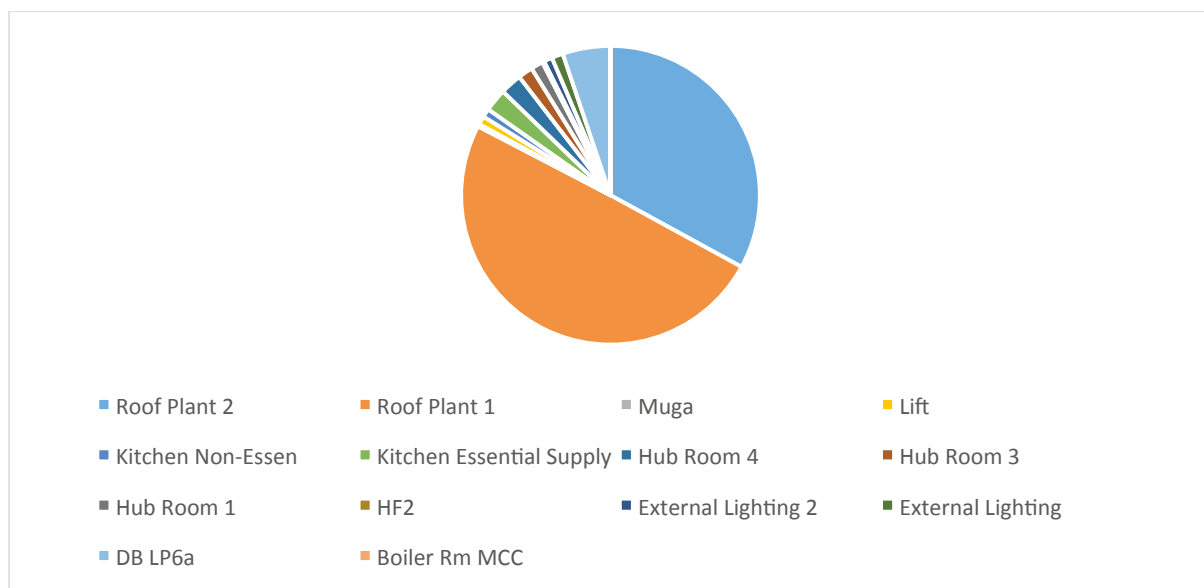


Figure 6: Sum of THD Current over 12-week period

The circuit breaker for the Multi-Use Games Area (MUGA), within the sports dock, had an on-going nuisance tripping issue. The facilities team could not identify the cause of this, but the cloud-based platform was able to detect the problem within a very short time period. The issue was due to the circuit breaker exceeding the current limit, as can be seen in Figure 7. The facility management team used the information extracted to redistribute the load and prevent further tripping.



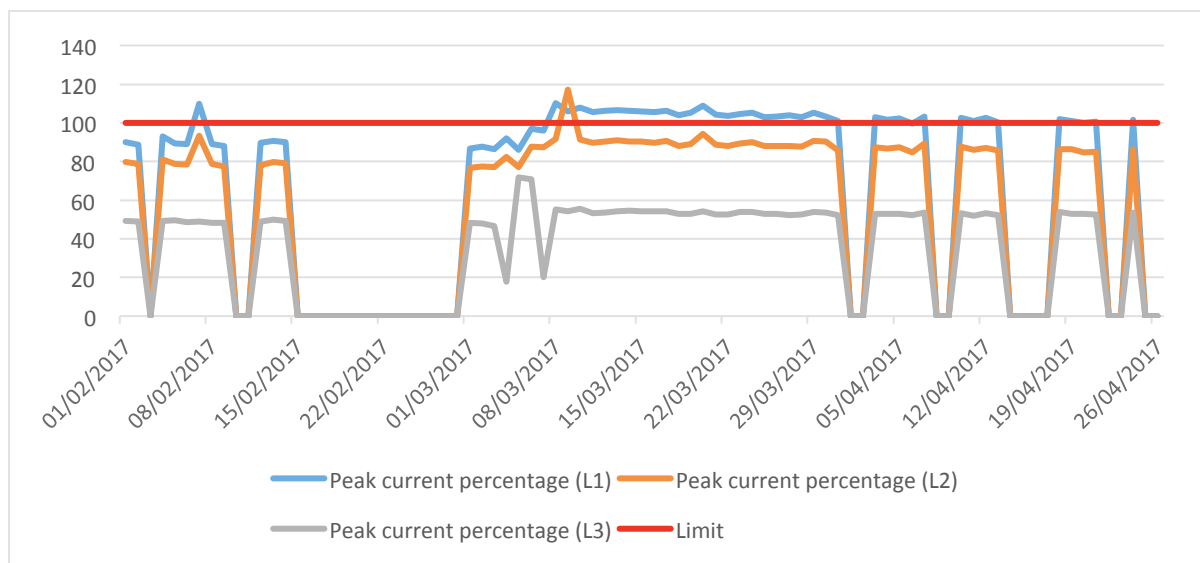


Figure 7: Multi Use Games Area (MUGA) current breaker limit as percentage

### DPD Parcel Sorting Hub Case Study

The DPD parcel sorting super hub in Hinckley, Leicestershire is a £100m facility built on 33 acres of land (DPD, 2017). The cloud-based platform was implemented in this commercial building following an extremely costly transformer failure. The platform identified that the sorting hub was experiencing very high THD on the network, over 5% (**Error! Reference source not found.**). According to IEEE Standard 519, THD should be less than 5% (Karti, 2017). This THD caused degradation of the insulation on the electrical transformer resulting in the failure, therefore a new transformer had to be installed on 25th March 2017. THD was then reduced due to the high impedance core of the new transformer, but the issue of high THD was not resolved downstream. The reduction of THD is of paramount importance if the new transformer is to perform as expected, thus the research has been used to advise DPD to install THD filters at the source, which in this case are the motors and power supply mounted on the sorting system.

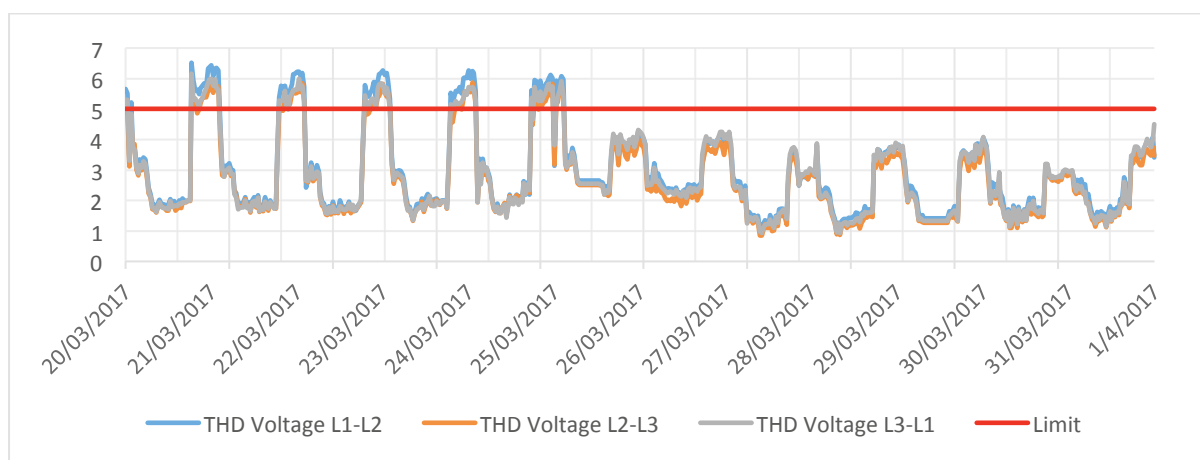


Figure 8: Total Harmonic Distortion (THD) at the DPD sorting hub

DPD also had problems with the new transformer being incorrectly configured after installation. The issue highlighted by the platform was a higher peak voltage configuration than was acceptable. This could have caused serious issues to the expensive sorting system over time. The cloud-based platform was able to show this and alert the facilities team immediately so that swift action could be taken. The transformer was reconfigured correctly on 29th March 2017 to a limit of below 440V, as can be seen in Figure 9.

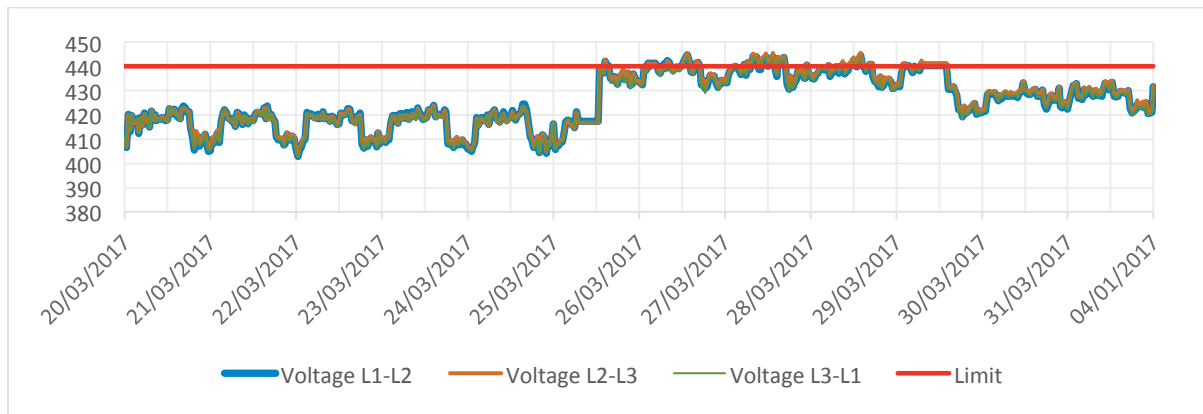


Figure 9: Output Voltage from the electrical transformer

### Oxygen House Case Study

Oxygen house is 40,000 square feet state of the art office building located in Exeter Business Park. It has been designed to a very high standard and been awarded a BREEAM rating of “Excellent” (Thorne, 2012). This building has a rainwater harvesting system, solar shading, solar hot water, solar panels to produce electricity, and electric car charging points. The BARM software platform identified one particular electric meter regularly exceeding 5% THD (as can be seen in Figure 10). Furthermore, the number of instances where THD exceeded 5% with respect to time is highlighted in Figure 11; where regular infractions were observed between 8:00am and 10:00am on weekdays. This pattern was due to usage of the electric car charging points – where most users plugged-in when they arrived to work in the mornings. These charging points are now being installed with a filter to lower the THD in the electrical system. According to (Kalair et al., 2017) THD filters can effectively reduce THD and can also improve power factor.

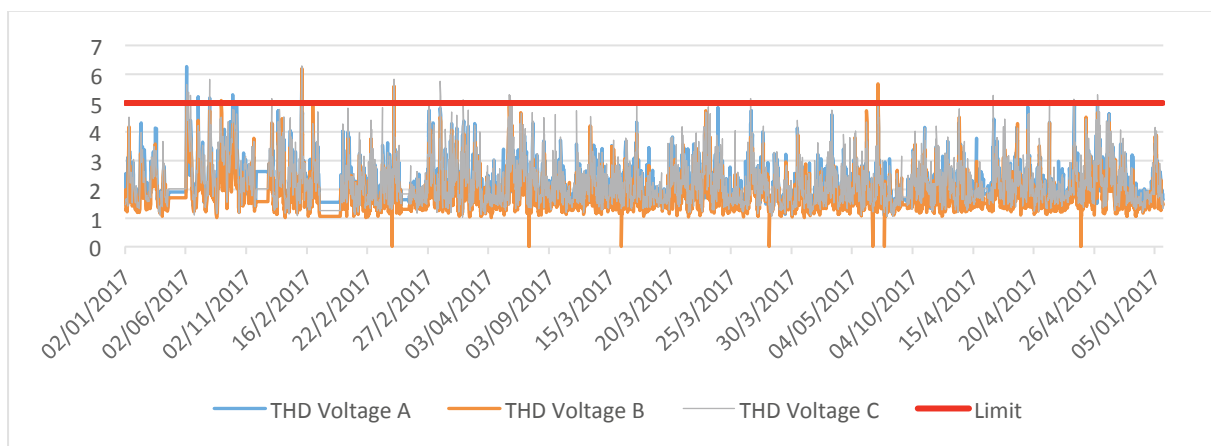


Figure 10: Total Harmonic Distortion (THD) of Oxygen house

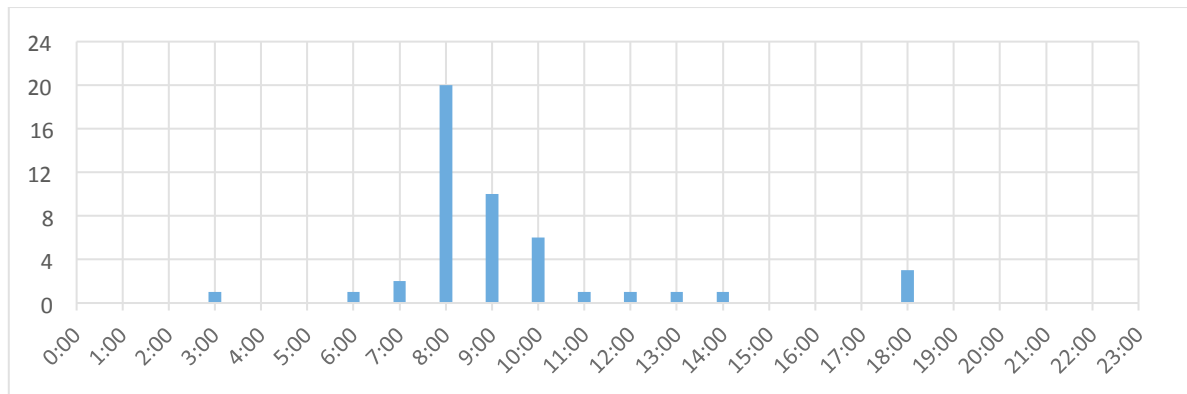


Figure 11: Count of Total Harmonic Distortion (THD) greater than 5%

## Conclusion

Modern commercial buildings heavily invest in electrical metering hardware but these are substantially underused, generally just extracting KWh. Each electric meter has the potential to provide many more data variables, which if analysed correctly, can support the development of pro-active, data-led actions to maximise the lifetime of the buildings' assets. This research project showed how a novel cloud-based platform could work by connecting commercial electric meters to the Internet – creating an Internet of Things (IoT) device that can extract real-time data for facility managers to monitor.

The case studies have highlighted the effectiveness of the cloud-based Building Asset Risk Management (BARM) application. Building owners and facilities managers have been able to increase energy efficiency through minimisation of energy usage and redistribution of electrical loads; as well as being able to identify the source of on-going issues in the electrical system using data from existing metering with no additional capital costs. The platform saves data in the cloud to allow access remotely, permitting monitoring without being physically in the building. The application also provides facility managers with information to predict MTBF (mean time between failures) of electrical assets by using power quality data.

The importance of such cloud-based applications will only increase in the future, as buildings and houses will be designed to be intelligent with more and more assets added to existing electrical systems. This intelligence will be developed by gathering data from meters and sensors mounted in the building and storing it in the cloud. This will allow for smart decisions to be made and further optimisation of the assets energy performance.

## References

- Ahmad, M. W., Mourshed, M., Mundow, D., Sisinni, M. and Rezgui, Y. (2016) 'Building energy metering and environmental monitoring - A state-of-the-art review and directions for future research', *Energy and Buildings*, 120, pp. 85-102.
- Al-Daraiseh, A., El-Qawasmeh, E. and Shah, N. (2015) 'Multi-agent system for energy consumption optimisation in higher education institutions', *Journal of Computer and System Sciences*, 81(6), pp. 958-965.
- AlFaris, F., Juaidi, A. and Manzano-Agugliaro, F. (2017) 'Intelligent homes' technologies to optimize the energy performance for the net zero energy home', *Energy and Buildings*, 153(Supplement C), pp. 262-274.
- Baggini, A. and Hanzelka, Z. (2008) 'Voltage and Current Harmonics', *Handbook of Power Quality*: John Wiley & Sons, Ltd, pp. 187-261.

Birkner, P. (2017) 'Opportunities of Big Data Tools in Smart Energy Systems', in Derksen, C. & Weber, C. (eds.) Smart Energy Research. At the Crossroads of Engineering, Economics, and Computer Science: 3rd and 4th IFIP TC 12 International Conferences, SmartER Europe 2016 and 2017, Essen, Germany, February 16-18, 2016, and February 9, 2017, Revised Selected Papers. Cham: Springer International Publishing, pp. 161-177.

DPD (2017) DPD UK - Europe's largest parcel hub officially opened ahead of 2015 peak. Available at: [https://www.dpd.com/home/news/latest\\_news/dpd\\_uk\\_europe\\_s\\_largest\\_parcel\\_hub\\_officially\\_opened\\_ahead\\_of\\_2015\\_peak](https://www.dpd.com/home/news/latest_news/dpd_uk_europe_s_largest_parcel_hub_officially_opened_ahead_of_2015_peak) (Accessed: 25/9/2017).

Escrivá-Escrivá, G., Porta, C. R. and De Jong, E. C. W. (2016) 'Nuisance tripping of residual current circuit breakers in circuits supplying electronic loads', Electric Power Systems Research, 131, pp. 139-146.

Fuchs, E. F. and Masoum, M. A. S. (2008) Power quality in power systems and electrical machines. London: Academic Press.

Hall, F. and Greeno, R. (2011) Building services handbook. 6th edn. Oxford: Butterworth-Heinemann.

Heselton, K. E. (2014) Boiler operator's handbook. 2nd edn. Lilburn, GA: The Fairmont Press.

Jayamaha, L. (2016) Energy-efficient industrial systems: evaluation and implementation. New York: McGraw-Hill Education.

Kalair, A., Abas, N., Kalair, A. R., Saleem, Z. and Khan, N. (2017) 'Review of harmonic analysis, modeling and mitigation techniques', Renewable and Sustainable Energy Reviews, 78, pp. 1152-1187.

Khalid, M. U., Bashir, M. K. and Newport, D. (2017) 'Development of a Building Information Modelling (BIM)-Based Real-Time Data Integration System Using a Building Management System (BMS)', in Dastbaz, M., Gorse, C. & Moncaster, A. (eds.) Building Information Modelling, Building Performance, Design and Smart Construction. Cham: Springer International Publishing, pp. 93-104.

Krarti, M. (2017) Energy-Efficient Electrical Systems for Buildings. Boca Raton: CRC Press.

Lee, D. and Cheng, C. C. (2016) 'Energy savings by energy management systems: A review', Renewable and Sustainable Energy Reviews, 56, pp. 760-777.

Lee, Y. M., An, L., Liu, F., Horesh, R., Chae, Y. T. and Zhang, R. 2013. Applying science and mathematics to big data for smarter buildings. Annals of the New York Academy of Sciences.

Li, B., Jing, Y. and Xu, W. (2017) 'A Generic Waveform Abnormality Detection Method for Utility Equipment Condition Monitoring', IEEE Transactions on Power Delivery, 32(1), pp. 162-171.

Mehta, R. and Parekh, K. 'Real life case studies on diagnosis and solutions of electrical network quality related problems'. Proceedings - 2015 IEEE IAS Joint Industrial and Commercial Power Systems / Petroleum and Chemical Industry Conference, ICPSPCIC 2015, 243-250.

Merabti, S., Draoui, B. and Bounaama, F. 'A review of control systems for energy and comfort management in buildings'. Proceedings of 2016 8th International Conference on Modelling, Identification and Control, ICMIC 2016, 478-486.

Minoli, D., Sohraby, K. and Occhiogrosso, B. (2017) 'IoT Considerations, Requirements, and Architectures for Smart Buildings-Energy Optimization and Next-Generation Building Management Systems', *IEEE Internet of Things Journal*, 4(1), pp. 269-283.

Mobley, R. K. (2002) *An introduction to predictive maintenance*. 2nd edn. Amsterdam; London: Butterworth-Heinemann.

Morales-Velazquez, L., Romero-Troncoso, R. D. J., Herrera-Ruiz, G., Morinigo-Sotelo, D. and Osornio-Rios, R. A. (2017) 'Smart sensor network for power quality monitoring in electrical installations', *Measurement: Journal of the International Measurement Confederation*, 103, pp. 133-142.

Nair, N. K. C. and Jing, L. (2013) 'Power quality analysis for building integrated PV and micro wind turbine in New Zealand', *Energy and Buildings*, 58, pp. 302-309.

Pan, J., Jain, R., Paul, S., Vu, T., Saifullah, A. and Sha, M. (2015) 'An Internet of Things Framework for Smart Energy in Buildings: Designs, Prototype, and Experiments', *IEEE Internet of Things Journal*, 2(6), pp. 527-537.

Popa, G. N., Iagăr, A. and Diniş, C. M. 'Some power quality issues in power substation from residential and educational buildings'. 2017 10th International Symposium on Advanced Topics in Electrical Engineering, ATEE 2017, 545-550.

Rondeau, E. P., Brown, R. K. and Lapedes, P. D. (2017) *Facility management*. 2nd edn. Hoboken, N.J.: John Wiley & Sons, Inc.

Santiago, I., Palacios-Garcia, E. J., Moreno-Garcia, I. M., Gil De Castro, A. and Moreno-Munoz, A. 'Appliances in the residential sector: Economic impact of harmonic losses'. 2017 11th IEEE International Conference on Compatibility, Power Electronics and Power Engineering, CPE-POWERENG 2017, 620-625.

Shahnia, F. and Ghosh, A. (2014) 'High Penetration of Rooftop Photovoltaic Cells in Low Voltage Distribution Networks: Voltage Imbalance and Improvement', in Hossain, J. & Mahmud, A. (eds.) *Renewable Energy Integration: Challenges and Solutions*. Singapore: Springer, pp. 69-95.

Sinopoli, J. (2016) *Advanced technology for smart buildings*. Artech House power engineering library Boston: Artech House.

Thorne, A. (2012) Prominent HQ building completed for Exeter-based researchers. Available at: <http://www.broadwaymalyan.com/press-releases-archive/2012/04/prominent-hq-building-completed-for-exeter-based-researchers?locale=en> (Accessed: 26/9/2017).

Truong, H.-L. and Dustdar, S. (2014) 'Sustainability Data and Analytics in Cloud-Based M2M Systems', in Bessis, N. & Dobre, C. (eds.) *Big Data and Internet of Things: A Roadmap for Smart Environments*. Cham: Springer International Publishing, pp. 343-365.

Van Vliet, M. T. H., Wiberg, D., Leduc, S. and Riahi, K. (2016) 'Power-generation system vulnerability and adaptation to changes in climate and water resources', *Nature Climate Change*, 6(4), pp. 375-380.

# Building Performance Optimisation for the Retrofit of a Council Tower Block in London

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**Abstract:** This study aims to optimise the building performance of a 22-storey tower block in London Borough of Newham (LBN) using energy efficient retrofitting strategies. Initial studies show that the water ingress issues within the tower block are mainly caused by a combination of inefficient building envelope and occupants' patterns of energy consumption in their homes. The first phase of this research analysed the performance of the tower block through indoor monitoring, occupants' interviews and building simulation in the winter season. The second phase of this project, the focus of this paper, studies two retrofit approaches of the tower block by applying EnerPHit standard, and the potential retrofit approach considered by LBN. The study builds on the results from the first phase by using building simulation to examine the reduction of heating loads and the improvement of indoor thermal comfort in the winter season when applying each retrofit strategy. The results show that improving the building envelope by using EnerPHit standard through significant improvement of the building fabric and incorporating Mechanical Ventilation and Heat Recovery (MVHR) systems, decrease the building heating energy loads to more than half of the actual energy consumption while keeping the indoor thermal environment within the standard comfort range. In addition, using LBN suggested thermal insulation material as the potential retrofitting strategy to improve the External Wall Insulation (EWI), reduces the energy consumption of the building to nearly half of the original heating energy loads, nearly similar to the first retrofitting approach in this study.

**Keywords:** EnerPHit, energy efficiency, retrofit, building performance, thermal comfort

## Introduction

Governments in many countries have put pressure to improve the energy efficiency and building performance to reduce the Greenhouse Gases (GHGs) emissions. Improving the energy efficiency of the built environment is one of the major priorities of the UK government in order to reduce energy demand and deliver on the carbon emission reduction plans. The government's long-term plan is to reduce greenhouse gases by eighty percent by 2050 (CCC, 2016). The energy use in the housing sector in the UK accounts for 29 percent of the total CO<sub>2</sub> emissions production (DBEIS, 2017); two thirds of this energy generated by space heating demand (Palmer and Cooper, 2012). In addition, the existing UK housing stock is considered one of the least energy efficient domestic buildings in Europe and therefore, contribute to carbon emissions significantly (Neroutsou and Croxford, 2016). The significant level of global carbon emissions shows that it is essential to take rapid and effective action to reduce the energy consumption in buildings. This could be achieved by implementing energy efficient retrofit strategies, which would increase property value and improve occupants' health and comfort while reducing fuel poverty (Neroutsou and Croxford, 2016, Vilches et al., 2017, Rickaby, 2011). Many studies have found that retrofit schemes have the economic benefit due to reducing building energy costs (Galvin and Sunikka Blank, 2013, Grimes et al., 2011). As a result, the energy loads for space heating and the comfort temperature in the cold seasons have been a focus of research in the UK (Rory et al., 2016).

However, many studies found that the benefits from retrofitting can be compromised through the building performance gaps where expected benefits may not necessarily tie with the actual improvement (Chitnis et al., 2013, Sorrell et al., 2009). Energy efficiency studies indicate that appropriate retrofit strategies can significantly improve the building energy



consumption and environmental performance. There have been successful retrofit programmes rolled out by the UK government's Department of Energy and Climate Change (DECC)– now Department of Business, Energy and Industrial Strategy (DBEIS) - to improve the energy efficiency of the buildings in the UK such as RE:FIT and RE:NEW programmes, which are two retrofitting schemes to cut the carbon emissions level in London (RE:NEW., 2012, Greater London Authority, 2017). RENEW programme is one of the relatively successful programmes which aimed to enhance the building energy performance and reduce the impact of fuel poverty in London homes (GLA, 2015) while RE:FIT scheme aimed to reduce the energy demands of the public buildings in the UK (Greater London Authority, 2017). One significant precedent is Kirklees Warm Zone (KWZ) scheme, which is one of the largest examples of such schemes completed in the UK, was the first to offer free loft and cavity wall insulation to all eligible properties (Edrich et al., 2011).

Studies show that in London Borough of Newham (LBN), there is a high rate of fuel poverty at 13.8 per cent (13,372 households) which is amongst the highest rates in the UK (Walker and Ballington, 2015b). Newham Council has been developing a plan to retrofit many of the council's residential buildings. Improving the energy efficiency of the buildings in the borough will cut the energy cost of the residential sector and reduce fuel poverty, meanwhile mitigating carbon emissions (Walker and Ballington, 2015a, Walker and Ballington, 2015b). The council's plan is to significantly reduce the number of tenants affected by fuel poverty in the domestic sector whilst achieving a minimum energy efficiency standard of B or C by 2030 (Bromley-Dery, 2015). There are also some risks associated with retrofit. The underperformance of retrofit projects can lead to major problems within the building(s) and their occupants' health. Damp, mould and condensation are the most common problems in some of the retrofitted buildings and as such, the buildings struggle to achieve indoor thermal comfort. Inappropriate building materials, lack of knowledge in the technical aspects of retrofit and inappropriate workmanship skills can lead to these problems (Deselincourt, 2015).

The current study is the second phase of the energy efficient retrofit study of one of the prototypes of LBN's council tower blocks. The 22-storey tower block comprises of 108 1-bedroom and 2-bedrooms flats. The initial field surveys conducted by the LBN Community and Infrastructure team highlighted some major damp and mould issues within many flats (Medhurst and Turnham, 2016). The survey also found water penetration concerns in the tower block. The first phase of this research focused on building performance evaluation and the interactions between the building performance of the flats, the occupants' energy consumption behaviour, and the indoor thermal comfort in the winter months of 2016-17 (Zahiri and Elsharkawy, 2017). This included on-site monitoring of indoor air temperature and relative humidity levels in addition to semi-structured interviews with the occupants. Along with the field studies, building simulation modelling using DesignBuilder (DB) software was performed to evaluate the building performance using the Met office weather data and the actual occupancy and energy patterns to understand possible reasons for dampness issues and the dissatisfaction of the occupants from the indoor thermal conditions. In the second stage of this study (the focus of this paper), the aim is to optimise the building performance of the same tower block, to develop guidance for LBN's planned retrofit. EnerPHit standards, and LBN recommended strategy have been tested to compare between the reduction of energy demands and the improvement of thermal comfort when using each strategy.

## Case Study & Methodology

The aim of this study is to optimise the building performance of the 22-storey council tower block in LBN (Figure 1) during the winter months. The study adopts a mixed method research design based on field monitoring, semi-structured interviews, and building simulation. At first stage, the building performance evaluation was performed to identify and diagnose the possible causes of the physical issues detected in several areas of the building mainly damp, mould, condensation and water ingress. This process entailed monitoring of indoor air temperature and Relative Humidity (RH) levels of a sample of flats in the case study and building simulation modelling to assess the building performance, the occupants' energy consumption behaviour and indoor thermal comfort. Two sample flats, identified as problematic, have been selected as the exploratory sample case studies for the research, with a particular focus on the bedrooms where most complaints emerged from. Building simulation modelling using dynamic Design Builder (DB) software was also undertaken to help further understand and diagnose the issues with the building performance detected by the data loggers, observations and occupants' interviews. The results confirmed that the occupants' energy consumption behaviour and the damage to the external over-cladding are the main reasons for the damp and mould issues that consequently resulted in poor indoor environmental conditions and concerns from the occupants about their comfort, health and wellbeing.

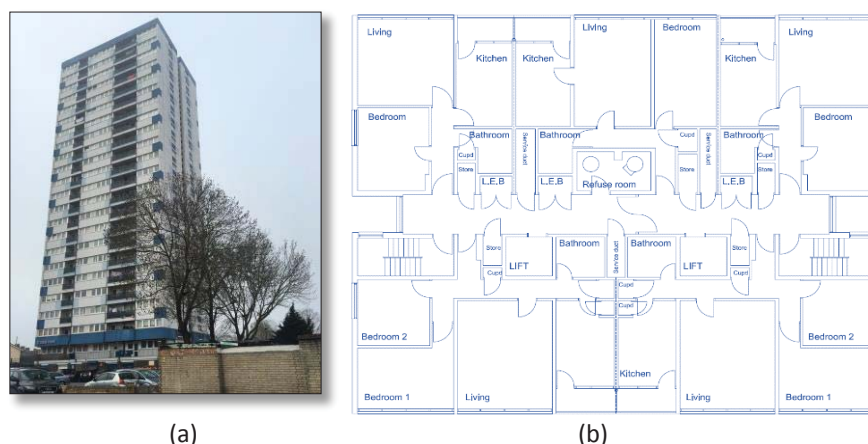


Figure 1. The case study tower block (a) and a typical floor of the case study building (b)

The second phase of the study (the focus of this paper) focuses on the building performance optimisation and methods for energy efficient retrofit. This includes building thermal and energy simulation analysis of the tower block. In this stage, two potential energy efficient retrofit strategies are investigated aiming to improve the thermal envelope and reduce the overall building energy consumption while providing a comfortable indoor environment. These recommendations can then be applicable to similar building prototypes in the UK. EnerPHit standard has been selected as one of the most efficient retrofit strategies for this tower block in order to reduce the heating energy demands. The main focus was the application of thermal insulation materials and the improvement of MVHR as well as upgrading the windows to triple glazing, which are already used in one of the recent major retrofitted council buildings in the UK; Wilmcote House in Portsmouth (Buckwell, 2012). In addition, the second retrofitting option is LBN's current retrofitting strategy to improve fit External Wall Insulation (EWI) using PermaRock thermal insulation and render system. In this study, these two strategies were applied to the simulation model separately and the results




of the analysis were compared against the current energy performance of the case study to identify the better approach to reduce the building energy consumption and improve the indoor thermal comfort.

### **Passivhaus Standard & EnerPHit**

Using the EnerPHit standard in the refurbishment and retrofit of the existing buildings can lead to extensive improvements in thermal comfort of the occupants, economic and thermal efficiency of the building and consequently reduces the carbon emissions production and energy consumption demands (Passive House Institute, 2016, Passive House Institute, 2015). Passive design of houses means a low energy and energy efficient building, which uses building architecture to minimise the energy consumption of the building and improves the thermal comfort. Based on Mikler et al (2009), the correlation of the local climate with the shape and the thermal performance of the building is one of the main consideration of passive house design. The foundation of passive house relies on natural sources of energy which consequently reduces the need for mechanical systems for indoor cooling, heating and lighting (Light House Sustainable Building Centre and Guido, 2009). Based on the passive design concepts, Passive House or Passivhaus (in German) standard depends on the low energy design concepts used in building design and construction to provide more energy efficient, comfortable and affordable places to live in. Passivhaus standard was developed by Passivhaus Institut in Germany in the 90's (Mead and Brylewski, 2010) and is one of the fastest growing, low energy standards used worldwide including the UK.

The main aim of Passivhaus standard is to reduce the heating and cooling demands of the building while improving occupants' thermal comfort. The main focus of this standard is specifically on the application of the high level of thermal insulation to the building envelope and increasing the airtightness of the building as well as incorporating MVHR (Mead and Brylewski, 2010). Because of various reasons, for the existing buildings, it is not feasible to achieve the Passivhaus standard and as a result, the Passivhaus Institut developed EnerPHit standard for certified energy retrofits with Passivhaus Components. The EnerPHit standard is the Passivhaus standard used for refurbishing and retrofitting of existing buildings (Passive House Institute, 2010). For quality assurance and verification of the specific energy values achieved, the buildings that use EnerPHit standard for retrofitting can achieve the "EnerPHit–Quality-Approved Modernisation with Passive House Components" certificate (Passive House Institute, 2010). Table 1 presents the typical EnerPHit criteria for the building components as well as heating energy demands benchmarks for cold and temperate climate zone.

Table 1. EnerPHit criterial for the building component in the cold and cool-temperate climatic regions for cold seasons (Passive House Institute, 2016)

Climate zone	Opaque envelope against ambient air		Windows (including exterior door)			Ventilation	Heating	
	Exterior insulation	Interior insulation	Overall		Glazing	Min. heat recovery rate (%)	Max. heating demand (kWh/m²a)	
			Max. U-value W/m²K		Solar heat gain coefficient (g-value)			
								
Cold	0.12	0.30	0.65	0.70	0.80	Ug - g*1.0 ≤ 0	80%	30
Cool-temperate	0.15	0.35	0.85	1.00	1.10	Ug - g*1.6 ≤ 0	75%	25

### **Building Performance Optimisation**

This paper focused on the building performance optimisation of the case study tower block during the winter season using the energy efficient retrofitting strategies. In this study, the

EnerPHit standard strategies used to retrofit of Wilmcote House (one of the tall council buildings in the UK) have been adopted to the case study building as one of the retrofitting options. Wilmcote House is one of the recent major retrofitted tall council buildings in Portsmouth (RockWool, 2016), which has the similar building structure to the case study building and also was built in the same period as the tower block. For retrofitting of Wilmcote House, the buildings envelope was improved by the application of external wall insulation materials as well as upgrading the windows to the triple glazed openings. In addition, the improved MVHR system was applied to the building. The main thermal insulation material used in Wilmcote House is REDArt system from RockWool with rendering (Robinson and Cartwright, 2016). The second retrofit strategy investigated is, LBN's current retrofitting option. LBN has suggested to improve the building's envelope by removing the existing external over-cladding and replacing it with PermaRock external thermal insulation with silicon render system (PermaROck Product Ltd, 2017).

It should be noted that the current structure of the case study tower block is in-situ reinforced concrete frame construction with floor slabs spanning between shear walls and pre-cast concrete panels covering the flank wall. The case study envelope is cladded with asbestos cement over-cladding panels. All flats have double glazed windows with UPVC panels. The internal partitions consist of the concrete blocks of 100 mm thickness and the external walls include external over-cladding of 9 mm thickness, the 80 mm air gap, the 200 mm pre-cast concrete panels and the 20 mm internal wall insulation boards and finishes. The building heating is provided by natural gas hot water boilers and also there is one extractor fan in the kitchen and another in the bathroom. The current external over-cladding system of the case study tower block was excluded from the simulation model while testing the effect of retrofitting strategies on building performance. In addition, in this study, CIBSE TM59 (CIBSE, 2017) and SAP 2012's (DECC, 2014) heating and occupancy patterns were used in the simulation modelling as the UK government's standard and CIBSE technical memorandum, which were suggested to be used for the typical UK domestic sector's occupancy and energy patterns. In the first stage of this study (Zahiri and Elsharkawy, 2017), it was successfully demonstrated that using the heating and occupancy patterns suggested by CIBSE TM59 and SAP 2012 are acceptable patterns to be used in the simulation modelling for this project.

### ***EnerPHit Standard Strategy***

In this study, the EnerPHit standard strategies used in Wilmcote House were applied to the case study tower block as one of the retrofitting options. Wilmcote social housing block in Portsmouth is one of the major Passivhaus projects in the UK that used the EnerPHit standard for retrofitting of the existing building. The Wilmcote House was built in late 60s and the building structure includes the prefabricated concrete panels, similar to the case study tower block. The building consists of three connected eleven-storey residential blocks including 107 properties and was retrofitted by Portsmouth City Council to achieve very low energy demands to meet the EnerPHit standard (Crawford et al., 2014). The original building was poorly constructed and had a poor concrete prefabricated structure and would not have been lasted long if no refurbishment was undertaken. Similar to the case study building, the openings, the roof and the building's envelope as well as the heating system were required to be replaced to reduce the building's energy and the maintenance cost. As mentioned previously, the case study tower block has the significant water ingress issues which also was the case for Wilmcote House (Buckwell, 2012). As there is a similarity in the buildings' structure and also both buildings face the same thermal and energy performance matters, it

was decided to implement the Wilmcote House EnerPHit standard to the case study model in DB to assess the building's optimisation. It should be noted that Portsmouth City Council aimed to reduce the Wilmcote House annual heating and hot water demands by 90% and increase the life of the building to minimum of 30 years using the Passivhaus retrofitting strategies (Crawford et al., 2014).

For assessing the improvement of building performance of the tower block using Wilmcote EnerPHit standard strategies, it was decided to remove the existing external over-cladding system of the tower block in the simulation model and replacing it with the new insulated over-cladding using the EnerPHit standard. In addition, MVHR installation was also considered, as well as replacing the double glazed windows with the triple glazed openings to increase the energy efficiency of the building, similar to Wilmcote House. For the retrofit of Wilmcote House, the RockWool insulation products were used as EWI including RockPanel cladding façade system, a combination of REDArt External Wall systems and flat roof system, which also were considered for the case study tower block (Table 2). The REDArt external wall insulation will ensure excellent thermal performance and exceptional air tightness, reducing the occurrence of draughts, condensation and mould growth (RockWool, 2016), which are the issues of the case study.

Table 2. Specification of the materials used to improve the external wall performance of Wilmcote House (Cartwright, 2016)

Materials	Rockwool Quilt	Rockwool flexi	Cement board	REDArt system insulation	REDArt system rendering
<b>Thermal Conductivity</b> (w/m-K)	0.044	0.038	0.16	0.036	0.83
<b>Density</b> (Kg/m <sup>3</sup> )	60	45	950	110	1800
<b>Thickness</b> (mm)	75	175	12	100	8

Based on RockWool limited (2016), before retrofitting of this building, more than half of the occupants were not satisfied with the indoor thermal environment and a significant number of the properties suffered from damp, mould, condensation, inefficient and expensive heating and cold draughts which affected a few occupants health. Portsmouth City Council aimed improve the buildings energy efficiency and the occupants' thermal comfort by using the EnerPHit standards for retrofitting of this building, which are the main targets of this project.

### ***LBN Current Retrofit Strategy***

The second retrofitting strategy used in this study is the application of LBN's current retrofitting option. LBN considers using PermaRock EWI system to improve the building performance in order to reduce the energy demands and improve the indoor thermal condition, which also eliminates the issues related to dampness and condensation. PermaRock systems have been designed for use on high-rise and low-rise buildings as well as traditional and non-traditional forms of construction with latest technology (PermaRock Product Ltd, 2017). In DB simulation modelling, the current external over-cladding system of the case study was replaced by PermaRock EWI with the silicon rendering (Table 3).



Table 3. Building insulation material considered for retrofitting of the case study tower block by LBN  
(PermaROck Product Ltd, 2017)

Components	PermaRock Mineral Fibre Insulation	PermaRock Silicon K/R Finishes
<b>Thermal Conductivity</b> (w/mK)	0.036	0.800
<b>Density</b> (Kg/m <sup>3</sup> )	110	700
<b>Thickness</b> (mm)	250	4

## Results and Discussion

In this study, building optimisation of the council tower block in LBN during the winter season has been studied to provide tailored recommendation for the energy efficient retrofit for the domestic buildings in this area. The first phase of this study showed that although indoor air temperature and RH levels were in the comfort range during the winter season in 2016-17, the occupants were not satisfied with the indoor thermal condition. In addition, the initial phase of this project showed that the occupants thermal and energy behaviour have an effect on the level of dampness causing the occupants dissatisfaction. It was also suggested that improving the occupants' energy consumption behaviour can reduce this issue while reducing the total heating energy use of the building. However, the long-term solution would be energy efficient retrofit, which is the second phase of the study and also the focus of this paper.

In the second stage of this project, applying the EnerPHit standard strategies and LBN's current retrofit strategy to the case study tower block were studied using DB simulation tool to increase the building's energy efficiency in the cold seasons. Along with the council's current retrofit strategies, it was also decided to use the EnerPHit standard strategies, which were already tested in the similar type of council building in the UK; Wilmcote House in Portsmouth. This building has been retrofitted recently and the project is planned to complete in 2017. To test the case study building's performance in DB tool, the current external over-cladding system was removed from the original simulation model and the EnerPHit standard strategies and LBN's suggested retrofitting option were separately applied to the simulation model. As mentioned previously, the preferred thermal insulation material with silicon render system by LBN is PermaRock and the insulation materials used by Wilmcote House is REDArt system from Rockwool. In addition, in Wilmcote House, the building's energy efficiency was improved by applying the energy efficient MVHR system as well as upgrading the glazing to the triple glazed windows, which were both considered for the EnerPHit strategies of the case study.

Figure 2 presents the indoor air temperature of a typical middle floor of the case study tower block in the coldest week of winter 2017 after the application of EnerPHit strategies and LBN's suggested retrofitting strategy using TM 59 and SAP 2012 energy and occupancy patterns. It can be seen that the indoor air temperature was increased using both retrofitting strategies but they were still in the comfort range. Based on CIBSE Guide A (2016), the recommended comfort temperatures for the dwelling are considered between 17 °C with clothing value of 2.5 clo and 25°C with clothing value of 1clo. The EnerPHit standard resulted in more increase in the indoor air temperature mostly because of the thickness of the insulation materials as well as the use of improved MVHR and the triple glazed windows. LBN's strategy also increased the indoor air temperature comparing to the current state of the building. In addition, both retrofitting strategies reduced the indoor air temperature's



fluctuation comparing against the current state of the building. This shows that the current heating energy use pattern can be modified in order to decrease the heating energy consumption while still keep the indoor air temperature in the acceptable comfort range. The most suitable modified heating patterns for this building will be studied at the later stage of this project.

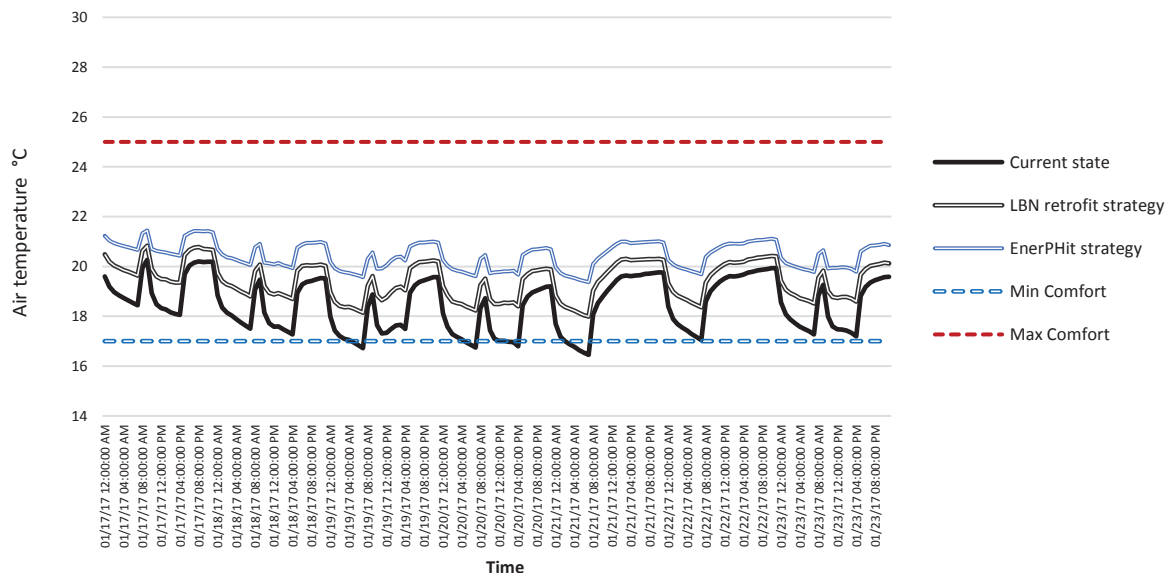


Figure 2. DB predicted indoor air temperature using various strategies in a typical middle floor of the case study tower block (Authors using DB, 2017)

Table 4 presents the U-value of the external wall using both retrofitting strategies comparing against the current state of the external wall. It can be seen that the U-value of the external wall using both strategies were improved significantly and as a result, the indoor air temperature was increased. The original U-value of the building was around  $0.80 \text{ W/m}^2\text{K}$  which is dropped to around  $0.1 \text{ W/m}^2\text{K}$  using both retrofitting strategy. However, the EnerPHit standard strategies caused more improvement comparing to the LBN's option. This also proves that the heating demand of the building can be decreased using both retrofit strategies because of having better U-value, while still keeping the indoor thermal condition in an acceptable range specially using the EnerPHit strategy.

Table 4. U-value of the case study external wall with different strategies applied to DB (Authors using DB, 2017)

Strategy	Current State	EnerPHit (Wilmcote House)	LBN Current Retrofit Strategy
U-Value ( $\text{W/m}^2\text{K}$ )	0.78	0.09	0.13

Building performance enhancement in the case study building in the winter season reduced the monthly heating consumption of the case study tower block (Figure 3), which is dropped to nearly half of the estimated energy loads for the current state of the building; from over 64000 kWh to around 30000 kWh. As mentioned before, the phase one of this project proved that one of the reason of the dampness issues in the case study building, which increases the heating energy loads in the winter season, is the jet-washing of the external over-cladding that damaged the sealing between the panels facilitating a path for water to penetrate the concrete structure during periods of driving rain. This problem causes dissatisfaction of the occupants from the indoor thermal conditions in cold seasons and the increase of the energy use to improve the indoor thermal condition. Using the suggested retrofitting strategies, can improve the dampness issues as the building external envelope airtightness will be improved

due to use the suggested thermal insulation materials, which will also reduce the energy use of the building and consequently reduce the energy bills. Figure 3 shows that the reduction of the energy loads of the building using the EnerPHit strategies is a bit more than using the LBN retrofitting strategy. This is because of using the triple glazed windows as well as the improved MVHR system in the EnerPHit Standard strategies along with external thermal insulation while in LBN strategy, the focus was only on improving the external wall's thermal insulation materials.

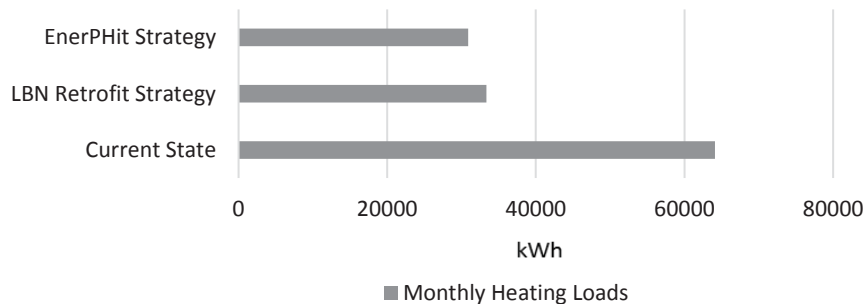


Figure 3. Monthly heating loads of the case study tower block using different retrofitting strategies in the winter months (Authors using DB, 2017)

This study also shows that both retrofit strategies reduced the heat loss of the building through the building's envelope in the cold period. Enhancing the heat balance of the building during the winter season reduces the zone sensible heating and consequently the heating loads of the building. In addition to the reduction of the heating energy loads in the tower block (Figure 3), the heat loss and the heat gain of the tower block were also improved, using the EnerPHit and LBN current retrofitting strategies, which confirms the advantage of using these two options for the retrofitting of the case study tower block. It should be noted that MVHR and triple glaze windows were considered as the EnerPHit strategies for the case study building. However, they were excluded from the simulation model using LBN strategy as the council prefers not to improve the current MVHR and glazing systems of the building. Figure 4 illustrate the heat balance of the tower block in the typical coldest day in the winter season using two retrofitting strategies comparing against the current building state. It should be noted that the heat loss and the heat gain through the floor, partitions and ceiling were excluded from the figure, as the difference between the results was very negligible.

It can be seen that the application of EnerPHit strategies decreased the heat loss through the glazing significantly, almost one third of the current state of the building which has a double glazed windows. This improvement is due to the use of triple glazed windows. In addition, adding the thermal insulation materials to the external wall of the building using both LBN and EnerPHit strategies reduced the heat loss to nearly one sixth of the current state of the building's envelope, which is very significant and consequently the zone sensible heating of the building and the heating loads reduced as well. This reduction is more than a half using EnerPHit strategies as the MVHR and glazing system of the case study building were also improved. However, LBN's strategy reduced the zone's sensible heating around one third of the original one as the focus was only on the improvement of the thermal insulation materials and the render system of the external walls. Nevertheless, using both strategies have a significant effect on the improvement of the buildings heating energy consumption and thermal condition. Based on the cost analysis of these two strategies as well as the effect of these strategies on CO<sub>2</sub> emission level, the most suitable retrofitting strategies will be

selected for the energy efficient refurbishment, which is currently studied for the final stage of this project.

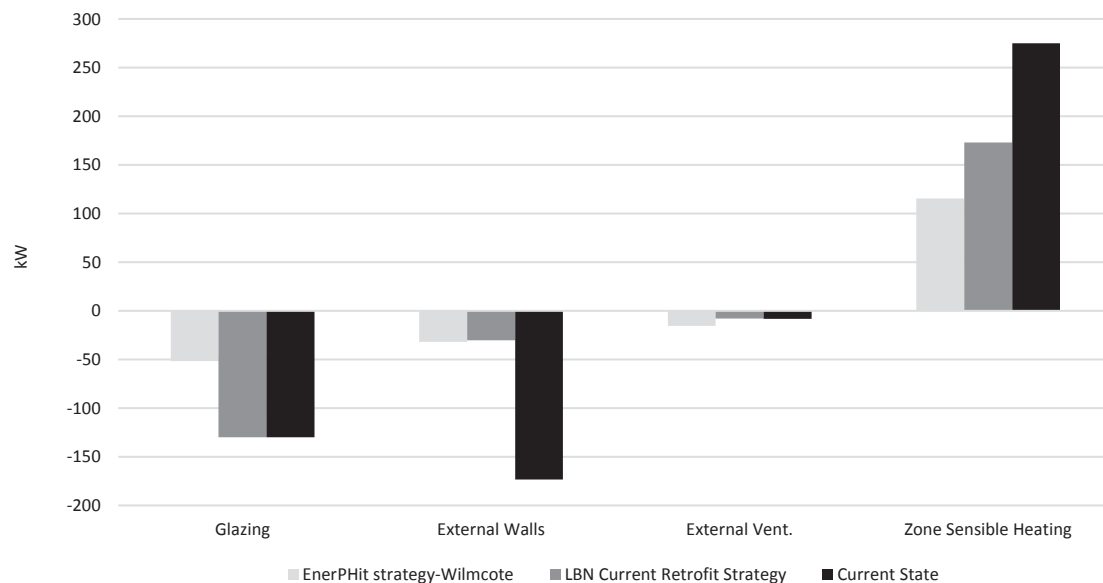


Figure 4. Hourly heat balance in the case study block in a typical coldest winter day (Authors using DB, 2017)

## Conclusion

This study is the second phase of a research project which aims to improve the building performance and energy efficient retrofitting of the council tower block. Phase one of this project focused on the building performance evaluation which included field monitoring of thermal comfort variables and semi-structured interviews with the occupants concerning their energy consumption behaviour and their thermal comfort satisfaction. In addition, building simulation analysis was also performed to evaluate the case study tower block to be validated for the second phase of this project for the retrofitting of the building. One strategy was using the EnerPHit standard while the second strategy was using LBN's current retrofitting option.

To optimise the building performance, each retrofit strategy was applied to the case study tower block using DB simulation tool. Later, the effect of each strategy on thermal and energy performance of the building was assessed against the current overall performance of the building. The impact of both strategies on the heating energy demands and heating balance of the tower block were compared against the current performance of the building in the winter months. The EnerPHit system adopted used REDArt system to improve the building envelope efficiency along with triple glazing as well as incorporating MVHR system. However, LBN suggested to use its recommended insulation materials with the silicon render system as their proposed retrofitting strategy.

The results show that both strategies improved the building thermal and energy performance significantly in the winter months compared against the current building state. The indoor air temperature and the heat balance of the building during the typical winter season were enhanced, which resulted in reducing the overall energy use of the building. The study shows that the application of the external thermal insulation to the building's envelope

using both strategies reduced the U-value of the external wall from around 0.8 W/m<sup>2</sup>K to around 0.1 W/m<sup>2</sup>K and as a result, reduced the need to mechanical heating system. In addition, the application of EnerPHit strategies decreased the heat loss through the glazing to almost one third of the current heat loss through glazing of the building due to the use of triple glazed windows and reducing it to around -52 kW. Adding the thermal insulation materials to the external wall of the building using both LBN and EnerPHit strategies reduced the heat loss through the envelope to nearly one sixth of the current state of the building's and reducing it to around -30 kW and consequently, the zone sensible heating of the building and the heating loads reduced significantly. This reduction is more than half at around 115 kW using EnerPHit strategies as the MVHR and glazing system of the case study were also improved. However, LBN's strategy reduced the zone's sensible heating around one third of the original one as the focus was only on the improvement of the thermal insulation materials and the render system of the external walls, which is around 170 kW.

As the EnerPHit standard is based on the stricter U-values, and higher insulation level, it could be an optimum alternative to reduce energy consumption. In addition, the EnerPHit strategies have more effect on reducing the heating loads, as in addition to the external thermal insulation, the double glazed windows were upgraded to triple glazed windows and the MVHR system was also incorporated for the building retrofitting strategies. Overall, both retrofit strategies could be recommended to optimise the energy efficiency of the building, reduce energy demands, and maintaining indoor comfort levels. The decision will be affected by the cost of the intervention and the council's available budget for the project. Currently, the total cost of each intervention and the payback period are under study.

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## References

- BROMLEY-DERY, K. 2015. Home Energy Conservation Act (HECA) Return London.
- BUCKWELL, O. 2012. Wilmcote house cladding and refurbishment. Portsmouth: Portsmouth City Council.
- CARTWRIGHT, P. 2016. D3.9\_EnerPHit Retrofit Plan- CS14 Wilmcote House, Portsmouth. Darmstadt: Passive House Institute.
- CCC 2016. UK Climate Action following the Paris Agreement. London: Committee on Climate Change.
- CHITNIS, M., SORRELL, S., DRUCKMAN, A., FIRTH, S. & JACKSON, T. 2013. Turning lights into flights: estimating direct and indirect rebound effects for UK households. *Energy and Policy*, 55, 234-250.
- CIBSE 2016. Environmental Design, CIBSE Guide A. London, UK: Chartered Institution of Building Services Engineers.
- CIBSE 2017. TM59: Design methodology for the assessment of overheating risk in homes. London: The Chartered Institution of Building Services Engineers
- CRAWFORD, K., JOHNSON, C., DAVIES, F., JOO, S. & BELL, S. 2014. Demolition or Refurbishment of Social Housing? A review of the evidence. London: UCL.
- DBEIS 2017. Energy Consumption in the UK. Department for Business, Energy & Industrial Strategies.
- DECC 2014. SAP 2012- The Government's Standard Assessment Procedure for Energy Rating of Dwellings. Watford: BRE.
- DESELINCOURT, K. 2015. The Risk of Retrofit. *Green Building*, 28, 28-37.
- EDRICH, B., BEAGLEY, K., WEBBER, P. & KELLING, S. 2011. Kirklees Warm Zone: Final Report 2007-2010. Kirklees.
- GALVIN, R. & SUNIKKA BLANK, M. 2013. Economic viability in thermal retrofit policies: learning from ten years of experience in Germany3444. *Energy Policy*, 3, 43-351.

- GLA 2015. RE:NEW- Helping to make London's homes more energy efficient. London: Greater London Authority.
- GREATER LONDON AUTHORITY. 2017. *What is RE:FIT London?* [Online]. London: Greater London authority. Available: <https://www.london.gov.uk/what-we-do/environment/energy/energy-buildings/refit/what-refit-london> [Accessed 28th Sep 2017].
- GRIMES, A., YOUNG, C., ARNOLD, R., DENNE, T., HOWDEN-CHAPMAN, P., PREVAL, N. & TELFARBARNARD, L. 2011. Warming Up New Zealand: Impacts of the New Zealand Insulation Fund on Metered Household Energy Use. Wellington: Ministry of Economic Development.
- LIGHT HOUSE SUSTAINABLE BUILDING CENTRE & GUIDO, W. 2009. Passive Design Toolkit for Homes. Vancouver: Smart Power and Customer Care.
- MEAD, K. & BRYLEWSKI, R. 2010. Passivhaus primer: Introduction- An aid to understanding the key principles of the Passivhaus Standard. Watford: BRE Trust.
- MEDHURST, J. & TURNHAM, C. 2016. Damp Survey for London Borough of Newham. London.
- MIKLER, V., BICOL, A., BREISNES, B. & LABRIE, M. 2009. Passive Design Toolkit Vancouver: Power Smart and Customer Care.
- NEROUTSOU, T. I. & CROXFORD, B. 2016. Lifecycle costing of low energy housing refurbishment: A case study of a 7 year retrofit in Chester Road, London. *Energy and Buildings*, 128, 178-189.
- PALMER, J. & COOPER, I. 2012. United Kingdom Housing Energy Fact File. In: CHANGE, D. O. E. C. (ed.). DECC.
- PASSIVE HOUSE INSTITUTE 2010. EnerPHit- Certification as "Quality-Approved Energy Retrofit with Passive House Components" *Criteria for Residential-Use Refurbished Buildings* Darmstadt Passive House Institute.
- PASSIVE HOUSE INSTITUTE. 2015. *EnerPHit - certified retrofits with Passive House components* [Online]. Passive House Institute. Available: [http://www.passiv.de/en/03\\_certification/02\\_certification\\_buildings/04\\_enerphit/04\\_enerphit.htm](http://www.passiv.de/en/03_certification/02_certification_buildings/04_enerphit/04_enerphit.htm).
- PASSIVE HOUSE INSTITUTE 2016. Criteria for the Passive House EnerPHit and PHI Low Energy Building Standard. Darmstadt: Rheinstr.
- PERMAROCK PRODUCT LTD. 2017. *PermaRock\_External Wall Insulation for Existing Building* [Online]. Loughborough: PermaRock. Available: <https://www.permarock.com/ewi-for-existing-buildings>.
- RE:NEW. 2012. Roll-out Evaluation Report – 2011/12. London: Mayor of London.
- RICKABY, P. 2011. GUIDE 1: introduction to the low carbon domestic retrofit guides. *Building Opportunities for Business*. 1 ed. London: Institute for Sustainability.
- ROBINSON, A. & CARTWRIGHT, P. 2016. D3.8\_Evaluate Specialist Deep-Retrofit Products Report-Wilmcote House in Portsmouth. Darmstadt: Passive House Institute.
- ROCKWOOL. 2016. *Wilmcote House- Portsmouth* [Online]. RockWool. Available: <http://www.rockwool.co.uk/cases/wilmcote-house/> [Accessed 28th Sep 2017].
- RORY, V., JONES, A., ALBA FUERTES, A., CHRISTINE BOOMSMA, B & SABINE PAHL, B 2016. Space heating preferences in UK social housing: A socio-technical household survey combined with building audits. *Energy and Buildings*, 127, 382-398.
- SORRELL, S., DIMITROPOULOS, J. & SOMMERVILLE, M. 2009. Empirical estimates of the rebound effect: a review. *Energy Policy* 37, 1356–1371.
- VILCHES, A., BARRIOS PADURA, A. & MOLINA HUELVA, M. 2017. Retrofitting of homes for people in fuel poverty: Approach based on household thermal comfort. *Energy Policy*, 100, 283-291.
- WALKER, S. & BALLINGTON, R. 2015a. Domestic Energy Efficiency in Newham Annual Report 2013-4. London.
- WALKER, S. & BALLINGTON, R. 2015b. London Borough of Newham Annual Fuel Poverty Report 2013-14. London.
- ZAHIRI, S. & ELSHARKAWY, H. 2017. Building Performance Evaluation for the Retrofit of Council Housing in the UK: A case study of a tower block in London *PLEA 2017, Passive Low Energy Architecture- Design to Thrive*. Edinburgh: NCEUB 2017.

# Facade Retrofit of Residential Buildings: Multi-objective optimization of a typical residential building in Cairo

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**Abstract:** The population and the residential sector are continuously expanding especially in highly dense cities such as Cairo, Egypt. Due to high demand for cooling energy in the residential sector in Egypt recently, a great attention was paid to retrofit existing buildings to decrease reliance on air conditioning. The existing housing stock is suffering from poorly insulated buildings envelope and lack of energy conservation measures. This is mainly to minimize the initial cost of the construction process while available sustainable guidance is still not mandatory. However, yet façade retrofit solutions include a wide range of variables for wall insulation and glazing types. This study aims to identify best configurations of the building facade retrofit solutions to minimize energy consumption due to cooling and retrofitting cost. A multi-objective optimization was performed on a representative benchmark for typical residential buildings in Cairo using genetic algorithm in order to test different combinations of retrofit options that best meet study objectives. Simulation results were assessed and calibrated against monthly electricity bills using Design Builder as a graphical user interface for EnergyPlus. Best retrofit combinations were highlighted and tested using life cycle cost assessment, and then effective variables were prioritized based on a sensitivity analysis.

**Keywords:** Façade retrofit, residential buildings, multi-objective optimization, Cairo.

## Introduction

In the last few decades, Cairo witnessed a rapid increase in the rate of investments in the residential sector with response to population growth. The majority of these investments have been dedicated towards constructing residential buildings. Accordingly, residential buildings reached more than 70% of the total building stock in Egypt where 56% of total energy consumed in buildings is due to cooling (El-Darwish, 2017; Aldali, 2016). As well, a recent study showed that a sharp rise was noticed in the use of mechanical cooling, and in the increasing total number of sold A/C units (Ediesy and Cecere, 2017). According to Attia et al. (2012), the use of air-conditioning has raised the annual electricity bill by a range of 44% to 57% in residential buildings in Cairo.

Nowadays retrofitting existing buildings became a worldwide approach to overcome the huge amount of energy needed for cooling and heating loads. The existing housing stock in Egypt is suffering from poorly insulated buildings' envelope which is considered responsible for increasing cooling loads (Albadry et al., 2017). Therefore, existing residential buildings are considered a good opportunity for reducing cooling loads through retrofitting. In Egypt, there were some trials from the governments to apply a code for energy performance in buildings, but no guidelines were provided regarding retrofitting existing buildings (Attia and Herde, 2009).



According to He (2015), the main three categories of retrofit measures available in the market are; 1) improving the building envelope. 2) Improving heating, cooling, lighting and hot water systems. 3) Installing renewable energy systems. While the most of recent studies explored limited retrofitting solutions without comparing multiple configurations, or only focused on one parameter of building envelope such as window glazing (Ediesy and Cecere, 2017; El-Darwish and Gomaa, 2017; Albadry et al., 2017). The aim of this study is to identify best building façade retrofit configurations that provide highest energy savings with least initial cost using multi-objective optimization approach for typical residential building in Cairo.

## **Literature Review**

In order to figure out the best retrofitting solutions for any existing building stock, a better understanding of the buildings characteristics and its current energy performance is required (Singh, 2015). The energy consumption patterns in residential building stock in Egypt were explored by several studies which will be illustrated in the following section. The energy consumption patterns were discussed, in addition to previous experience in retrofitting solutions in Egypt. Moreover, multi-objective optimization of retrofitting buildings was investigated as an approach with generating enormous scenarios of solutions.

### ***Energy consumption patterns in Egypt***

Based on a survey of different residential apartments in Egypt, the building characteristics and electricity patterns were analysed (Attia et al., 2012). The building envelopes of most of the buildings investigated are not airtight, with single glazed openings, non-insulated walls and with no shading treatment.

### ***Retrofit Building Stock in Egypt***

Albadry et al. (2017) considered the energy performance of existing residential buildings in Cairo is poor due to the non-insulated walls, the use of single glazing with no shading devices and window leakage. Consequently envelope retrofit actions was explored including the use of double glazing windows instead of single glazing ones, low-emissivity films, wall thermal insulation boards, and replace the traditional foam sheets used for roof insulation with Tilefoam 2.5 cm thick. The simulation results of the retrofitted case using EnergyPlus showed that the annual electricity consumption has decreased from 66 MWh to 44 MWh (Albadry et al., 2017).

Glazing improvement was investigated by Ediesy and Cecere (2017) as an envelope retrofit approach to decrease cooling loads of the residential sector in Cairo using EnergyPlus. The investigated glazing strategies included thickness, color, number of layers and coating of glazing. The results showed that only glazing replacement can lead up to 16.5% savings in total energy consumption.

The close relationship between different retrofit variables and energy efficiency in 3 higher education buildings in Egypt was examined by El-Drawish and Gomaa (2017). A comparison between the base case and the retrofitted model showed that using metal louvers of 0.5 cm as solar shading can reduce energy consumption up to 23% on average, followed by 8% on average energy consumption reduction due to using double glazing with low-e 4/6/4 mm Argon filling, and the air tightness strategy reduced only 2%, while adding 0.05 m of EPS Expanded Polystyrene to external walls had almost no effect on average energy consumption (El-Darwish and Gomaa, 2017).

## Building Envelope Optimization

Due to the enormous variables of building envelope design parameters, a consideration has to be paid to the largest number of design possibilities and multiple configurations (Ascieno, 2016). Ascieno proposed an investigation using a multi-objective optimization to identify the most suitable sets of technical solutions for building envelope in order to provide the best compromise between transparent envelope solutions, thermal mass of the building and radiative characteristics of roof in simple residential building located in four different cities of the Mediterranean climate. The optimal solutions for each city were proposed. The minimum value for each objective was discussed according to the specific building envelope characteristics.

## Methodology

This paper investigates a set of various retrofitting configurations for typical residential façades in Cairo based on computer simulation. The goal is to explore best configurations that would minimize energy consumption due to cooling and retrofitting cost. A total number of 480 cases were simulated to test main façade parameters; exterior wall insulation and glazing types for different building-orientation directions. A Multi-objective optimisation using Design Builder (Version 5.0.3.007) has been adopted to automatically simulate and test all possible combinations until optimal set of retrofitting configurations (Pareto front) have been identified (DesignBuilder Software Ltd, 2014).

The proposed methodology is based on a benchmark model for typical residential buildings in Cairo developed by Attia et al. (2012). The benchmark has been developed based on a survey on residential building stock in Egypt. Since the focus of the study is to investigate the retrofitting solutions for the typical residential buildings, no attention was paid to the roof retrofit, therefore the middle floor was chosen as a representative for the typical energy consumption patterns for residential buildings in Cairo. While the study aims to minimize cooling electricity consumption, therefore the selected zones for optimization multiple retrofitting options would be applied only for the three conditioned zones in each apartment as shown in the Figure 1 according to the benchmark model.

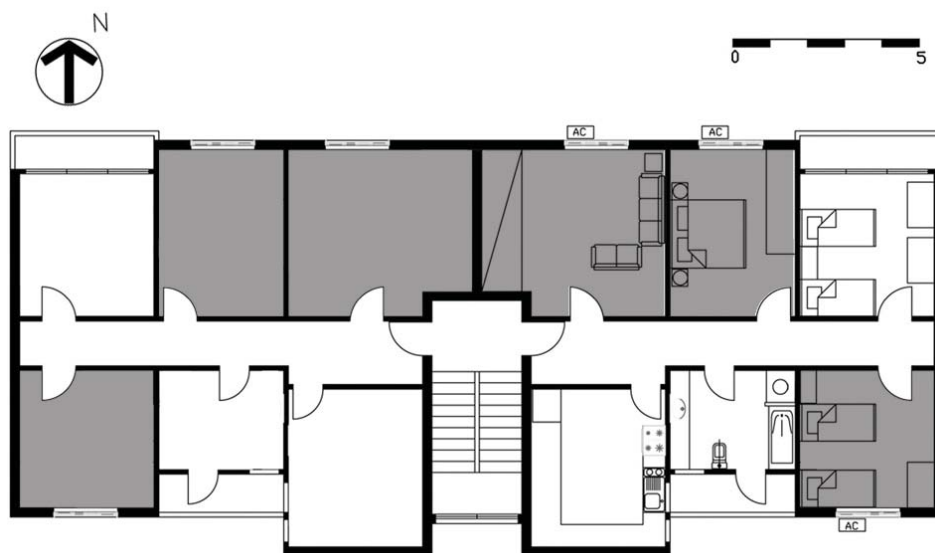


Figure 1. Base case floor plan, North-oriented case. The conditioned zones are highlighted.

### **Base Case Description**

The base case has been simulated as an intermediate floor with two apartments per floor using Cairo typical weather data. The benchmark simulation results were generated by averaging the four main orientations results in order to address the different orientations of the surveyed apartments. Each apartment is occupied by one family with total occupancy of 4-5 people and includes three bedrooms, a living room, a kitchen and a bathroom. The building uses reinforced concrete skeleton and brick walls. External and internal walls are 25cm and 12cm thickness respectively. Windows have wooden and metal frames with 3mm clear glazing of low thermal insulation properties, and infiltration was set to 0.7 ACH. Table 1 shows the building envelope solid elements and its characteristics. Airtightness is very low and infiltration can be observed through window frames. Suspended fluorescent lamps were assigned in almost all spaces except living rooms with incandescent suspended lamps. Lighting operation schedule is mainly dependent on space occupancy schedule which were investigated through the field surveys (Attia et al., 2012). Water heating is a minor energy consumer in Egyptian residential units since stand-alone water heaters with natural gas are commonly used to provide hot water in kitchens and bathrooms.

Table 1. Base case's building description (Attia et al., 2012).

<b>Building Description</b>	
Shape	Rectangular (25 m x 11m)
Floor height	2.8 m
Construction	Reinforced-concrete post and beam structure with brick infill walls without insulations
<b>Apartment Description</b>	
Total Floor Area (m <sup>2</sup> )	122
External Wall Area (m <sup>2</sup> )	110
Conditioned Floor Area (m <sup>2</sup> )	30
Conditioned Window Area (m <sup>2</sup> )	7

### **Model Calibration and Simulation Results Validation**

The simulation tool which was selected for this study is Design Builder (Version 5.0.3.007) which enables multi-objective optimization approach using EnergyPlus as a simulation engine. Design Builder provides a systematic framework to calibrate the model; it requires detailed definition of weather data, zone division, construction materials, openings, space activity & occupancy rates, light & equipment, domestic hot water, natural ventilation rates and HVAC systems (Ediesy and Cecere, 2017). The base case was modelled and simulated to test its thermal behaviour then was checked with the surveyed monthly electricity consumption from the benchmark as shown in Figure 2. Since one of the objectives of the study is to explore the retrofitting cost, the cost of the base case was set to zero, consequently any changes applied in the optimization process would easily be calculated as a retrofitting cost.

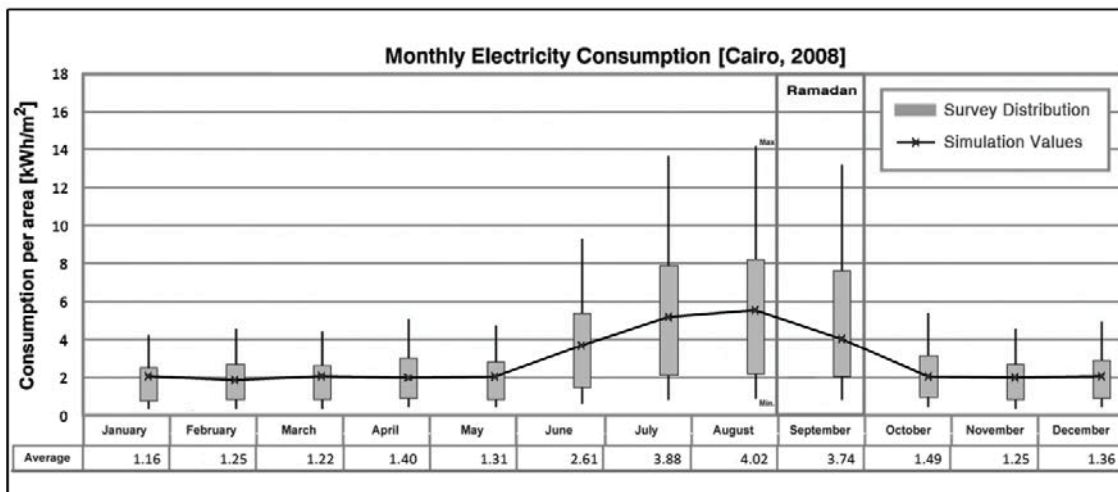


Figure 2. Validation of the simulated results of the base case against the previous survey (Attia et al., 2012).

### Tested Façade Parameters

#### Wall insulation

Extruded polystyrene sheets are commonly suggested as an efficient way in hot arid climates when used for insulation in the outer envelope of buildings (Attia and Herde, 2009). 11 alternatives of wall configurations were developed using multiple thicknesses of extruded polystyrene as a thermal insulation layer, including supplementary 12cm wall as an isolated thermal mass either with extruded polystyrene sheets or air gap. The proposed alternatives of wall configurations are illustrated in Table 2. Initial costs were based from local suppliers submitted on October 2017. The offers were submitted in Egyptian Pound "1 USD = 17.69 EGP" (Central Bank of Egypt, 2017).

Table 2. Wall construction-Layers configurations with benchmark (base case) highlighted.

Base Case (Thickness in mm)	Added Layer 1 (Thickness in mm)	Added Layer 2 (Thickness in mm)	U-value W/(m²·K)	Retrofitting Price (EGP /m²)
Brick (250 mm)			1.811	0
Brick (250 mm)	EPS (20 mm)	Gypsum Board (12.8 mm)	0.912	164
Brick (250 mm)	EPS (40 mm)	Gypsum Board (12.8 mm)	0.626	187.5
Brick (250 mm)	EPS (60 mm)	Gypsum Board (12.8 mm)	0.477	211
Brick (250 mm)	EPS (80 mm)	Gypsum Board (12.8 mm)	0.385	235
Brick (250 mm)	EPS (100 mm)	Gypsum Board (12.8 mm)	0.323	258
Brick (250 mm)	EPS (20 mm)	Brick (120 mm)	0.845	59
Brick (250 mm)	EPS (40 mm)	Brick (120 mm)	0.594	82.5
Brick (250 mm)	EPS (60 mm)	Brick (120 mm)	0.485	107
Brick (250 mm)	EPS (80 mm)	Brick (120 mm)	0.373	130
Brick (250 mm)	EPS (100 mm)	Brick (120 mm)	0.314	153
Brick (250 mm)	Air Gap (120 mm)	Brick (120 mm)	1.199	39

#### Window Glazing

Direct solar radiation during summer in Cairo is 0.8 kW/m² between 9:00am and 7:00pm while maximum solar radiation occurs at midday 0.86 kW/m². Diffuse horizontal solar

radiation maintains a stable value of 0.11 kW/m<sup>2</sup>. In summer, solar gains from exterior windows and glazing add up to 20 kWh load in inner spaces. Replacement of existing window glazing is an efficient method to decrease summer heat gain, cooling loads in conditioned spaces and discomfort hours in unconditioned spaces. The case study's current glazing is single 3mm clear glass with thermal transmittance of 5.894 W/(m<sup>2</sup>-K) and Solar Heat Gain Coefficient (SHGC) of 0.861 (Ediesy and Cecere, 2017). The proposed glazing alternatives are illustrated in Table 3. Retrofitting prices for the last 4 cases, include an additional aluminium framing price of 1250 EGP/m<sup>2</sup>. It has to be noted that all single glazing options are assumed to be retrofitted on the existing window frame. Initial costs were based from local suppliers submitted on October 2017.

Table 3. Glazing types. Benchmark base case is highlighted.

Glazing Types	U-value W/(m <sup>2</sup> -K)	SHGC	TVIS	Retrofitting Price (EGP /m <sup>2</sup> )
Single Clear 3mm (Base Case)	5.894	0.861	0.898	0
Single Clear 6mm	5.778	0.819	0.881	250
Single Grey 6mm	5.778	0.602	0.431	350
Single Blue 6mm	5.778	0.62	0.57	400
Single Ref-A-M Clear 6mm	5.065	0.218	0.14	400
Single I Ref-A-M tinted 6mm	4.664	0.261	0.09	450
Double Clear 6mm/13mm Air	2.665	0.703	0.781	2080
Double Grey 6mm/13mm Air	2.665	0.478	0.381	2280
DbI Ref-A-M Clear 6mm/13mm Air	2.301	0.185	0.127	2380
DbI Ref-A-M tinted 6mm/13mm Air	2.301	0.167	0.082	2480

### ***Life-Cycle Costing Assessment (LCCA)***

There are different methodologies for the calculation of the Life Cycle Cost (LCC) of an asset. The present value method is the most important and common method as it compares alternative configurations based on the same lifespan. It depends on converting all the future and annual cost into present value and this requires inflation and interest rates to be considered (Heteba, 2009).

The feed-in tariff was accounted as 1.022 EGP/kWh; it represents the just price for the production of electricity to residential end-users; with no subsidization nor taxation (Al-Ahram, 2017). LCC was performed for the period of 15 years, with the inflation and interest rates set to 16% and 12% respectively, and was calculated using the following equation:

$LCC = \text{Initial Cost of retrofitting} + \text{Electricity bills for } N \text{ years} + \text{Maintenance} + \text{Residual Value}$

- Initial Cost of retrofitting is calculated through multiplying the area of walls insulated and the new window construction, with the respective case of retrofitting cost rates as described in tables 2 & 3.
- Present value (P.V.) of Electricity bills has been calculated through the typical formula of geometric series as follows:

$$\text{P.V. Electricity bills} = \text{Current Annual Bill} \times \frac{1-(r)^n}{1-r}$$

Where  $n$  is the number of years for the study (15) and  $r$  is the multiplying factor accounting for inflation and interest rates ( $\frac{1.16}{1.12}$ ).

- Maintenance costs were ignored since the applied retrofitting alternatives don't need maintenance.
- Residual value is assumed to be 25% of the initial cost of retrofitting, after the period of the LCC study.

### Simulation Results and Discussion

Different retrofit combinations of façade parameters were investigated to identify the best configurations which minimize energy consumption due to cooling and retrofitting cost. Simulation results were used to produce guidelines for façade retrofit of residential buildings in Egypt.

The following graph in Figure 3 shows the optimization results for North-oriented case, such that each point represents a certain configuration (retrofitting scenario) of a glazing construction and a wall construction. Each scenario is evaluated according to the retrofitting cost (y-axis) and the corresponding cooling energy (x-axis). Best fitting options with least cooling energy and least capital cost of retrofitting are highlighted (Pareto front).

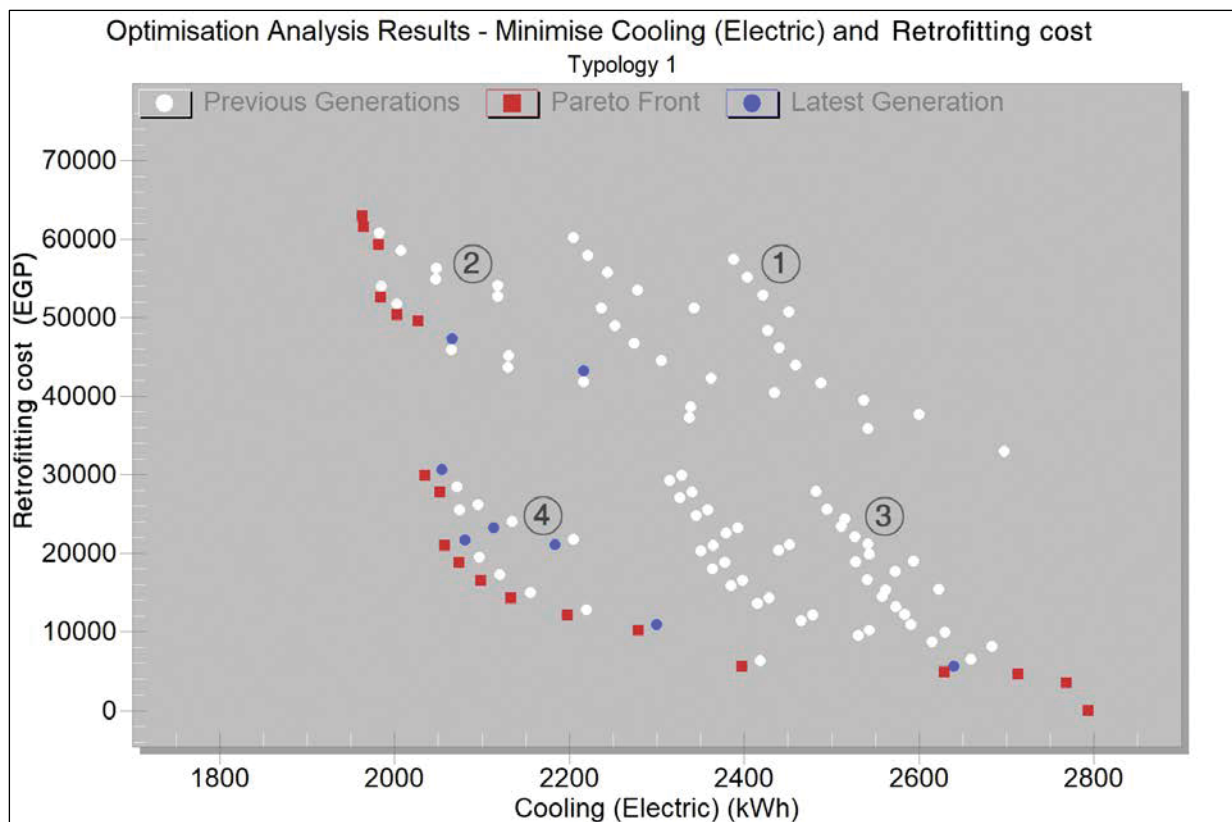


Figure 3. Optimization results for North-oriented case, with optimal configurations highlighted in red (Pareto Front).

### Retrofitting Solutions Comparison

The graph shows four separate clusters that formed naturally along the evolution of best results. Through the examination of each cluster constituting configurations, a pattern has been deduced as follows. Cluster (1), which shows worst results in terms of both cooling energy and capital cost, has only two window types; Double Clear 6mm/13mm Air and



Double Grey 6mm/13mm Air. Cluster (2), which shows best results along the cooling energy objective, has only the two window types; Double Reflective Clear 6mm/13mm Air and Double Reflective tinted 6mm/13mm Air. Cluster (3), which shows best results along the capital cost objective, has only the four following window types; Single Clear 3mm (Base Case); Single Clear 6mm; Single Grey 6mm and Single Blue 6mm. Finally, Cluster (4), which shows best fitting results in terms of both cooling energy and capital cost, has only the two windows types; 6mm Single reflective clear glazing and 6mm Single reflective tinted glazing, with the former only showing in the Pareto front. This is expected, as they are the window construction options with lowest u-value, also having 6mm thick glazing, which requires no new window framing. Cluster groupings were totally dominated by windows construction type. This is expected due to the very high cost of windows retrofitting in comparison to walls retrofitting, as well as the relatively high solar heat gain factor of the glazing.

In addition, Table 5 is showing solutions with the order of feasibility (minimum LCC). It is evident that among the feasible retrofitting solutions, the less economical wall constructions are found to have a thick EPS layer (80/100mm) or a gypsum board layer. This is expected for their relatively high cost. It is also to be noted that 3 out of the 16 feasible retrofitting solutions use the base-case wall construction, with only a glazing retrofitting scenario.

Moreover, Table 4 compares between feasible retrofitting solutions for different building-orientation cases, it is obvious that West and East oriented retrofitting scenarios have high impacts of retrofitting solutions results, while savings in annual energy consumption per apartment reach 14.4 % and 12.5% respectively. However, a macro perspective on all retrofitting solutions in all building-orientation cases shows that retrofitting costs range from 1,750 to 31,500 EGP, to save from 12 to 738 kWh annually per apartment (1-39% of the base case cooling energy consumption).

Table 4. Feasible retrofitting solutions according to LCCA per apartment for different building-orientation cases.

Orientation	Count of feasible retrofitting solutions	Feasible retrofitting solutions		Optimum saving in EGP (LCC)
		Savings range in total energy consumption (%)	Savings range in cooling energy (%)	
North	16	2 to 8.9	6 to 26	2,418
East	35	3 to 12.5	8 to 32	5,846
South	33	2.1 to 10.6	6 to 30	3,742
West	40	3.4 to 14.4	8 to 35	7,532

### ***LCCA study results***

Table 5, states the optimal solutions for North-oriented case, ordered according to the least LCC values. It shows 16 more feasible solutions than the base case of no-retrofitting scenario.

A sensitivity analysis on different LCC lifespans shows that for 12, 15 and 20 years, the North-oriented case offers possible money saving by 1225, 2418, and 6061 EGP respectively; while for the West-oriented case offers the best money saving by 4435, 7532, and 13656 EGP respectively.

## Conclusion

The existing residential buildings in Cairo are suffering from poorly insulated buildings' envelope which is responsible for increasing cooling energy consumption. However, retrofitting existing buildings became a worldwide approach to overcome the huge amount of energy needed for cooling and heating. The aim of this study is to identify best building façade retrofit configurations that provide highest energy savings with least initial cost using multi-objective optimization approach for typical residential building in Cairo.

According to the optimization results, four different clusters that formed naturally along the evolution of best results could be observed. The pattern which shows best fitting results has only the two window types; 6mm Single reflective clear/tinted glazing. The optimal solutions for the North-oriented case were ordered according to the least LCC values, it shows 16 more feasible solutions than the base case of no-retrofitting scenario, it is also to be noted that 3 out of the 16 feasible retrofitting solutions use the base-case wall construction, with only a glazing retrofitting scenario. In addition, a macro perspective on all retrofitting solutions shows that retrofitting costs range from 1,750 to 31,500 EGP, to save between 1-39% of the base case cooling energy consumption annually per apartment. Buildings with conditioned spaces oriented to East or West have high potential opportunities to achieve energy savings by facade retrofitting implementation. Results showed that West-oriented scenarios have high impacts of retrofitting solutions results, while savings in annual energy consumption per apartment reach 14.4 %, and 35% of savings in energy consumption due to cooling.

Although the simulation results could help in extracting general findings such as determining highly ranked solutions with minimal initial cost but conducting simulation in the process of design optimization is still necessary for decision makers and designers to make some trade-offs and identify optimal solutions based on a variety of parameters and variables.

It is quite obvious from the LCCA and the different lifespan comparison that the initial retrofit cost is the most challenging factor. Cheap retrofit combinations are highly ranked providing least LCC. The effect of the initial retrofit cost shrinks with longer LCCA lifespan. Therefore, one main objective when retrofitting building facades is the selection of cheap energy efficient materials. However, even if the retrofit combinations don't provide lower LCC than the base case, we should still promote for more retrofitting of existing building facades in order to help in dealing with global warming challenges. Finally, it is important to clarify that research findings are highly sensitive to the initial cost and energy tariff; any future changes in these aspects might lead to different optimal solutions.

## Further research

It's recommended for further research to include other design variables in consideration such as shading louvers, and window-to-wall ratio. Moreover, it could expand the scope of the study to other benchmarks that represent upper-middle-class and upper-class neighbourhoods that would find a faster and better pay-off for retrofitting. Finally, a national level could be introduced to offer greater perspective on possible environmental impact improvements (lower CO<sub>2</sub> emissions). In addition, it is important to consider saving equipment and lighting energy, for they consume around two thirds of total energy consumption in the benchmark used in this paper.

## References

- Al-Ahram. (2017). *Ministry of electricity announces today the new tariffs brackets, 102.2 piasters is the cost of producing Kilowatt-hour to households.* Available at: <http://www.ahram.org.eg/News/202317/27/602509/مصر-وزير-الكهرباء-يعلن-اليوم-أسعار-الشرائح-الجديدة---ق.aspx>
- Albadry, S., Tarabieh, K., & Sewilam, H. (2017). *Achieving Net Zero-Energy Buildings through Retrofitting Existing Residential Buildings Using PV Panels.* Energy Procedia, 115(Supplement C), 195–204.
- Aldali, K. M., & Moustafa, W. S. (2016). *An attempt to achieve efficient energy design for High-Income Houses in Egypt: Case Study: Madenaty City.* International Journal of Sustainable Built Environment, 5(2), 334–344.
- Ascione, F., De Masi, R. F., de Rossi, F., Ruggiero, S., & Vanoli, G. P. (2016). *Optimization of building envelope design for nZEBs in Mediterranean climate: Performance analysis of residential case study.* Applied Energy, 183(Supplement C), 938–957.
- Attia, S., & De Herde, A. (2009). *Impact and potential of community scale low-energy retrofit: case study in Cairo.* In: SASBE - Technical University Delft, 3rd CIB International Conference on Smart and Sustainable Built Environment (SASBE). Delft, Netherlands, June 2009. Delft: TU Delft.
- Attia, S., Evrard, A., & Gratia, E. (2012). *Development of benchmark models for the Egyptian residential buildings sector.* Applied Energy, 94(Supplement C), 270–284.
- Central Bank of Egypt. (2017). *Exchange Rates.* Retrieved October 14, 2017. Available at: <http://www.cbe.org.eg/en/EconomicResearch/Statistics/Pages/ExchangeRatesListing.aspx>
- DesignBuilder Software Ltd. (2014). *DesignBuilder Optimisation.* Retrieved October 14, 2017. Available at: <https://www.designbuilder.co.uk/optimisation/>
- Edeisy, M., & Cecere, C. (2017). *Envelope Retrofit in Hot Arid Climates.* Procedia Environmental Sciences, 38(Supplement C), 264–273.
- El-Darwish, I., & Gomaa, M. (2017). *Retrofitting strategy for building envelopes to achieve energy efficiency.* Alexandria Engineering Journal.
- He, M., Brownlee, A., Lee, T., Wright, J., & Taylor, S. (2015). *Multi-objective Optimization for a Large Scale Retrofit Program for the Housing Stock in the North East of England.* Energy Procedia, 78(Supplement C), 854–859.
- Heteba, N., (2009). *Life Cycle Cost and Assessment Model for Systems and Sources of Lighting.* MSc. The American University in Cairo.
- Singh, S. (2015). *Net Zero Energy Retrofit Using Calibrated Model, Optimization Techniques and Regression Graphs.* In: BS2015, 14th Conference of International Building Performance Simulation Association. Hyderabad, India, Dec. 7-9, 2015.

Table 5. Pareto Front configurations sorted by LCC per apartment for North-oriented case. Benchmark base case is highlighted. (Combinations sorted by LCC).

#	Window Construction	External wall Construction	Annual Electricity Consumption [kWh]	Capital Cost of Retrofitting [EGP]	LCC (present value method) [EGP]
1	Sgl Ref-A-M Clr 6mm	Dbl Solid brick wall, 250 mm, 20 mm EPS	3,850	6,043	79,819
2	Sgl Ref-A-M Clr 6mm	Dbl Solid brick wall, 250 mm, 40 mm EPS	3,818	7,156	79,823
3	Sgl Ref-A-M Clr 6mm	Solid brick wall, 250 mm	3,951	2,808	79,937
4	Sgl Ref-A-M Clr 6mm	Dbl Solid brick wall, 250 mm, 12 mm Air Gap	3,891	5,119	80,092
5	Sgl Ref-A-M Clr 6mm	Dbl Solid brick wall, 250 mm, 60 mm EPS	3,801	8,269	80,123
6	Sgl Ref-A-M Tint 6mm	Dbl Solid brick wall, 250 mm, 20 mm EPS	3,861	6,394	80,238
7	Sgl Ref-A-M Tint 6mm	Dbl Solid brick wall, 250 mm, 40 mm EPS	3,829	7,507	80,246
8	Sgl Ref-A-M Tint 6mm	Solid brick wall, 250 mm	3,961	3,159	80,344
9	Sgl Ref-A-M Tint 6mm	Dbl Solid brick wall, 250 mm, 12 mm Air Gap	3,902	5,470	80,505
10	Sgl Ref-A-M Clr 6mm	Dbl Solid brick wall, 250 mm, 80 mm EPS	3,789	9,382	80,520
11	Sgl Ref-A-M Tint 6mm	Dbl Solid brick wall, 250 mm, 60 mm EPS	3,812	8,620	80,539
12	Sgl Ref-A-M Tint 6mm	Dbl Solid brick wall, 250 mm, 80 mm EPS	3,800	9,733	80,956
13	Sgl Ref-A-M Clr 6mm	Dbl Solid brick wall, 250 mm, 100 mm EPS	3,780	10,495	80,995
14	Sgl Ref-A-M Tint 6mm	Dbl Solid brick wall, 250 mm, 100 mm EPS	3,792	10,846	81,429
15	Sgl Grey 6mm	Solid brick wall, 250 mm	4,066	2,457	82,023
16	Sgl Ref-A-M Clr 6mm	Solid brick wall, 250 mm, 40 mm EPS	3,808	11,636	82,212
17	Sgl Clr 3mm	Solid brick wall, 250 mm	4,148	0	82,237
18	Sgl Ref-A-M Clr 6mm	Solid brick wall, 250 mm, 20 mm EPS	3,843	10,523	82,263
19	Sgl Grey 6mm	Dbl Solid brick wall, 250 mm, 20 mm EPS	3,984	5,692	82,268
20	Sgl Blue 6mm	Solid brick wall, 250 mm	4,072	2,808	82,339
21	Sgl Grey 6mm	Dbl Solid brick wall, 250 mm, 12 mm Air Gap	4,017	4,768	82,382
22	Sgl Grey 6mm	Dbl Solid brick wall, 250 mm, 40 mm EPS	3,959	6,805	82,416
23	Sgl Ref-A-M Clr 6mm	Solid brick wall, 250 mm, 60 mm EPS	3,789	12,749	82,471
24	Sgl Blue 6mm	Dbl Solid brick wall, 250 mm, 20 mm EPS	3,991	6,043	82,599
25	Sgl Ref-A-M Tint 6mm	Solid brick wall, 250 mm, 40 mm EPS	3,819	11,987	82,622

# Influence of occupant behaviour on thermal comfort and energy use in Albanian homes

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**Abstract:** This paper focuses on occupants' behaviours that affect the energy and thermal performance of residential buildings in Albania. Results were extracted from monitoring of the building and occupant surveys in one selected bungalow in Tirana, a form-built that represents over 80% of residential buildings in Albania. It was built in the post-communist area and has a concrete block construction. An annual electricity consumption 35% higher than the average for Albanian houses was found and a high variation of indoor temperatures during summer and winter. Key reasons for these findings were occupants' behaviours, that were determined by occupants' lifestyle, preferences and perceptions of comfort as well as cultural factors. The lack of information regarding behaviours that decrease energy consumption, and the lack of determination to consistently practice what they knew, resulted in a high energy consuming and uncomfortable. Window operation was found to have the largest impact in energy load and achieving comfort. These findings strengthen the need to understand the relationship that residents have with their properties, as well as the socio-cultural context, in order to suggest energy retrofitting strategies that will be accepted, implemented and really work for them over their lifetime in the properties. These results should be used to inform and validate the baseline energy modelling rather than using untested assumptions to minimise the performance gap between the expectations and outcomes created at the design stage.

**Keywords:** Occupant behaviour, energy performance, thermal comfort, monitoring, retrofit

## Introduction

Buildings are one of the biggest energy users, consuming over one-third of final global energy and nearly half of the electricity consumption (EEA, 2011; IEA, 2013; IPCC, 2014). Across Europe, high performance building retrofits have already demonstrated the ability to deliver up to 90% reduction in energy consumption, hence, improving the building stock can be the best measure to achieve energy efficiency (BPIE, 2011). In particular, residential buildings offer great potential for standardization, while improving comfort and achieving energy savings. As in many countries in Europe, improving the existing stock in Albania is considered as the highest potential contributor to the energy saving targets of the National Energy Efficiency Plan (Energy Community, 2011), given the fact that building sector is the second largest energy consumers in Albania with over 40% of total energy consumption (Energy Community, 2015; Global Buildings Performance Network, 2015), with residential buildings consuming 30% of the total energy consumption. Most of this energy, about 40%, is used for space heating (Shehi, Gjoka and Schweizer, 2011) and the average electricity consumption is 4600kWh per household per year (International Energy Agency, 2008).

Although Albania, as a developing country, has no obligations towards reducing any quantity of greenhouse gas emissions (United Nations Human Rights, 2015), the built area and the energy consumption in the building sector is expected to increase as a result of the continuous development of the country. Therefore, a special consideration is given to these countries, recognizing the importance of reducing emissions and building resilience to climate change impacts on them (European Commission, 2016).

In this acknowledged reality, where improving the energy performance of existing housing stock provides the greatest potential to energy savings, several energy retrofitting programs have shown that they are lower than anticipated (Gupta and Gregg, 2012; Sunikka-Blank and Galvin, 2012), even when they are technical and financial viable. Buildings not only influence the final energy consumption through the technical energy efficiency of the product itself, but they also influence energy consumption through the way they structure the practices of the householders (Vlasova and Gram-Hanssen, 2014). On the other hand, their performance is complex, depending on a number of different technical and non-technical factors that can change over time (Janda and Topouzi, 2015). It is founded that even for neighbouring houses with nearly identical construction, the energy consumption may vary dramatically (Gram-Hanssen, 2013; Ingle et al., 2014), because houses are for people and people behave in different ways and there is no 'standard' household (Shove, Pantzar and Watson, 2012). Different occupants living in exactly the same type of house, can have energy consumption that changes by a factor of three or more mainly because occupants behave in more complex ways than designers account for (Janda, 2011), suggesting that it is the user that determines the energy consumption in homes (Gram-Hanssen, 2010). Furthermore, 'habits' can lead to a constant daily routine followed by the households, emphasizing the difference in requirements for different households (Guerra-Santin et al., 2016). However, the statement from (Janda, 2011) 'Buildings don't use energy: people do' has finally shifted the attention from the building to the people living in it.

This paper evaluates the energy and thermal performance of a case study bungalow using a mixed-method approach. Occupant feedback is cross-analysed with physical measurements and monitoring during heating and cooling season to draw a set of findings that will influence the way houses will be retrofitted in Albania.

## **Methodology**

A socio-technical approach was used to collect quantitative and qualitative data through building surveys, occupant surveys and in-situ monitoring of indoor temperature (every 30 minutes) from one case study bungalows in Tirana. The case study is selected among 49 residential buildings studied, part of an ongoing doctoral research on retrofitting residential buildings in Albania, as one of the most common building form, but also as an example of a household with some common cultural issues affecting its energy behaviours. External temperature was also measured to make the right investigation of the set inside temperature. Data was collected into two rounds, from June 2016 to August 2016 (round 1, 47 days) and from January 2017 to February 2017 (round 2, 42 days), to gather empirical data about the energy and thermal performance of the houses, and occupants' perspective, to get insights of how and when the house is used, occupants' attitudes and habits, as well as to assess their comfort sensation and preference in summer and winter. Electricity use data were also collected for one year using fuel bills.


## ***Case study's characteristics***

In Albania, there are 598,267 residential buildings containing 1,012,400 dwellings in total (Instat, 2012). The housing stock has been developed in line with the political, social and economic phases of the country. Most of them are the product of a quick and cheap construction strategy because of the housing shortage during the communist regime and after, from the rapid urbanization that happened after '90, which had no intention in the quality of life of their occupants. 80% were one-storey detached houses, with only one



dwelling. The case study house is located in Tirana and is built in 1994. It has a concrete block construction, and has gone through a partial renovation two years ago, including a 30mm EPS external insulation on the external walls. However, although the homeowner undertook the intervention purely to stop the moisture on the external walls, it was not completely achieved because of cold bridges created with other uninsulated elements of the construction (floor, roof and windows). Detailed information regarding the case study is given in Table 1.

Table 1: Case study information

	
Typology	Bungalow built after 1990
Year built	1994
Area (m <sup>2</sup> )	103m <sup>2</sup>
Number of bedrooms	Three
Orientation	North-East (front façade)
Occupancy	Four adults
Occupancy patterns	Weekdays: 07:00-17:00 25% 17:00-07:00 100% Weekends: 24h
Walls:	Hollow concrete blocks with 30mm EPS insulation on the outside and sand cement render in both sides, U-value: 0.85W/m <sup>2</sup> K
Roof	Un-insulated pitched roof, U-value: 2.93W/m <sup>2</sup> K
Floor	Uninsulated concrete floor with ceramic tiles, U-value: 0.8W/m <sup>2</sup> K
Windows	Single glazing with aluminium frames, U-value: 5W/m <sup>2</sup> K

## Energy performance

Biomass and electricity were used to heat the space, while cooling was performed using air conditioning devices. However only electricity consumption data were provided from electricity bills for a full year, given in Table 2 and Figure 1. It is noticed that electricity consumption of the house is nearly 35% higher than average electricity use for a house in Albania (4,600kWh).

Table 2: Energy consumption of the case study houses

Electricity consumption	January-December 2016
Total (kWh/year)	7,055
Total (kWh/m <sup>2</sup> /year)	68.5
Total treated (kWh/ m <sup>2</sup> /year)	140

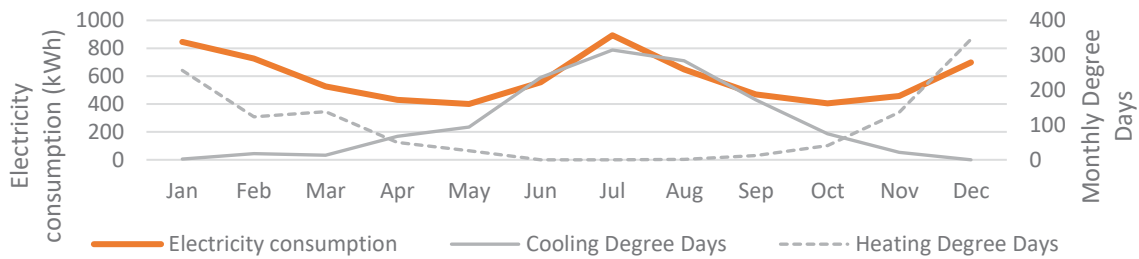


Figure 1: Electricity consumption from January-December 2016  
Source of degree days: (www.degree-days.net, 2017)

Using an electric boiler 24h for heating domestic water and using electric devices to heat and cool the space (in several rooms) are the main reasons for the high electricity consumption of house. Furthermore, multiple non-efficient appliances (Figure 2) were present in the house and electricity was used for cooking. Characteristics for energy use in each house is given in Table 3.



Figure 2: Example of appliances present in the house

Table 3: Characteristics for energy use

Lighting	Mix of fluorescent and incandescent lights
Appliances	Multiple appliances (two TV, two fridge-freezers, two laptops and a desktop computer)
DHW	Continuously on electric boiler
Cooking	Electric oven/hob
Heating	Inverter air conditioner (Living room and bedroom 1), oil filled radiator (bedroom 2) and biomass woodstove in bedroom 3
Cooling	Air conditioning (living room and bedroom 1)

### Environmental and thermal performance in summer

External and indoor temperature of living room and two bedrooms of the house were monitored from 30th of June to 12th of August 2016 at half-hourly intervals, to cover the hottest season of the year in the Albanian climate. The outdoor temperature ranged between 19.6°C to 41.1°C (with a mean temperature of 29°C), while the indoor temperature ranged (24.5°C-33.5°C) in the living room, (24°C-29.5°C) in bedroom 1 and (24°C-33.5°C) in bedroom 2, well above the recommended temperatures from the guidelines (23°C -25°C) for living rooms and 21°C-23°C for bedrooms) (CIBSE, 2006).

However, the mean daily temperatures have been between 28°C and 30°C most of the time, as shown in Figure 3. The graph indicates the use of air conditioning in the living room and bedroom 1, while the temperatures in bedroom 2 have almost the same profile as the

external temperature, meaning that this room has hardly been cooled at all. Table 4 presents the descriptive statistics in the main spaces during the summer.

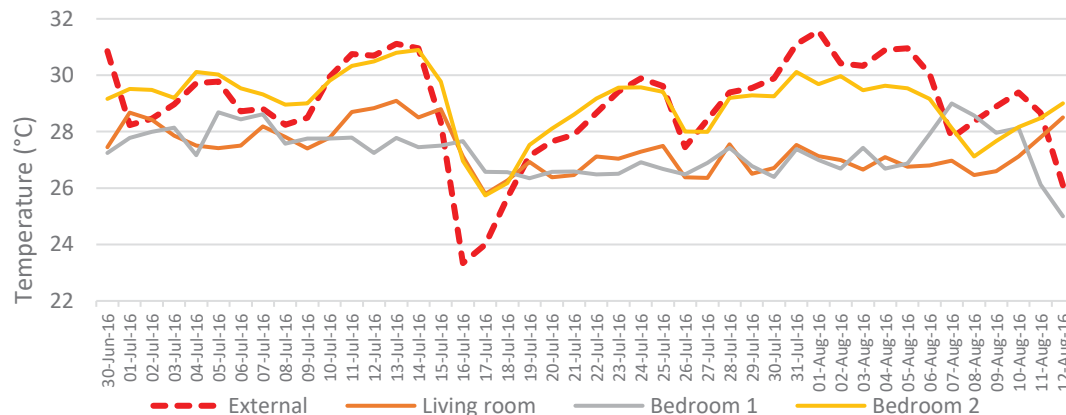


Figure 3: Mean daily temperatures in summer

Table 4: Descriptive statistics of indoor and external daily mean temperatures in summer

	Mean (°C)	Maximum (°C)	Minimum (°C)	Percentile 25 (°C)	Percentile 75 (°C)	St. Dev
External	28.97	31.60	23.30	28.25	30.15	1.78
Living room	27.36	29.10	25.80	26.75	27.80	0.80
Bedroom 1	27.29	29.00	25.00	26.65	27.80	0.81
Bedroom 2	29.03	30.90	25.70	28.35	29.65	1.13

Hourly indoor temperatures averaged over the monitored period revealed that air conditioning has been used almost all day as shown in Figure 4. The living room has been cooled almost all day, with a peak in the evening, when there is the maximum occupancy in the house. The main bedroom has also been cooled most of the day. All the rooms were overheated as they had temperatures over 25°C all the time. Furthermore, temperatures over 28°C for more than 20% of the occupied hours in the treated rooms and over 50% of the time in the non-treated bedroom. Temperatures exceeding 25°C occurs for 5% of the occupied hours (and 28°C/1%) is the guidance for assessing overheating (CIBSE, 2006).

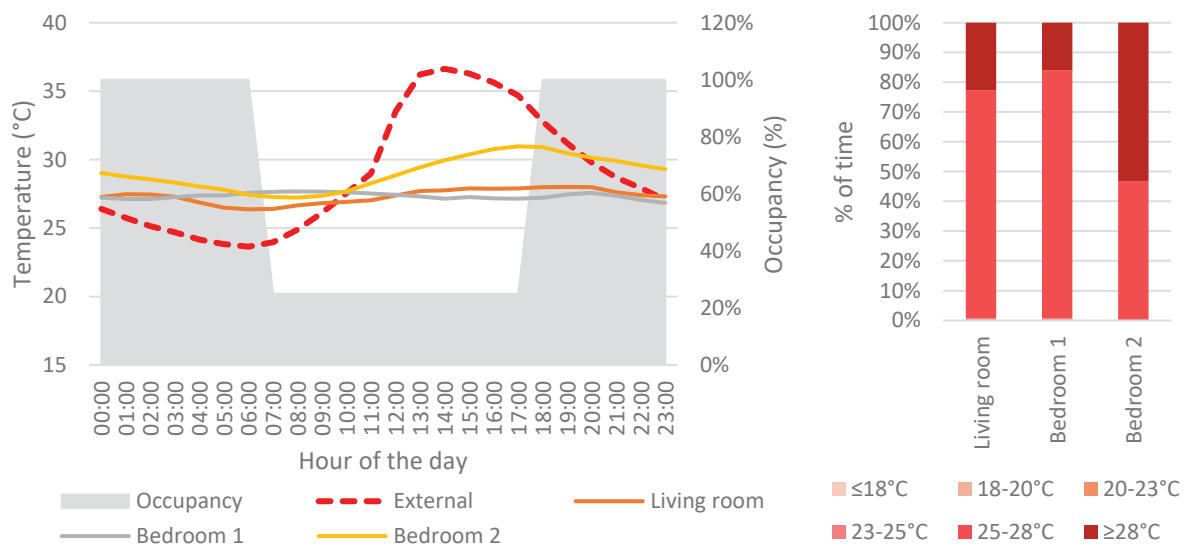


Figure 4: Mean temperatures during the day

Subjective evaluation of the thermal environment was collected by the homeowner of the house using a 7-point ASHREA scale for the thermal sensation evaluation and a 5-point scale for thermal preference. The survey showed that the occupant who completed it were feeling hot during the summer and wanted to feel much cooler. Because the questionnaire was time-stamped, it was found that indoor temperature at the time of completion was 27.8°C.

### Environmental and thermal performance in winter

Indoor temperature of living room and two bedrooms of the house were monitored from 5th of January 2016 to 16th of February 2017 at half-hourly intervals, to cover the coldest season of the year in the Albanian climate. The outdoor temperature ranged between -5.5°C to 18.5°C (with a mean temperature of 7.8°C), while the indoor temperature ranged from 6.5°C to 23.5°C in living room and from 11°C to 26.5°C and from 6°C to 21°C in bedroom 1 and 2 respectively. The indoor temperature has reached values well under the recommended temperatures from the guidelines of 22°C -23°C for living rooms and 17°C-19°C for bedrooms (CIBSE, 2006). Furthermore, the indoor temperature variation is very high.

The daily average profiles in Figure 5 show that the external average temperatures have reaches temperatures below 0°C, while it did not exceed 15°C. Bedroom 1, in difference to the living room and bedroom 2, has been heated all the time. Table 5 presents the descriptive statistics in the main spaces during the winter.

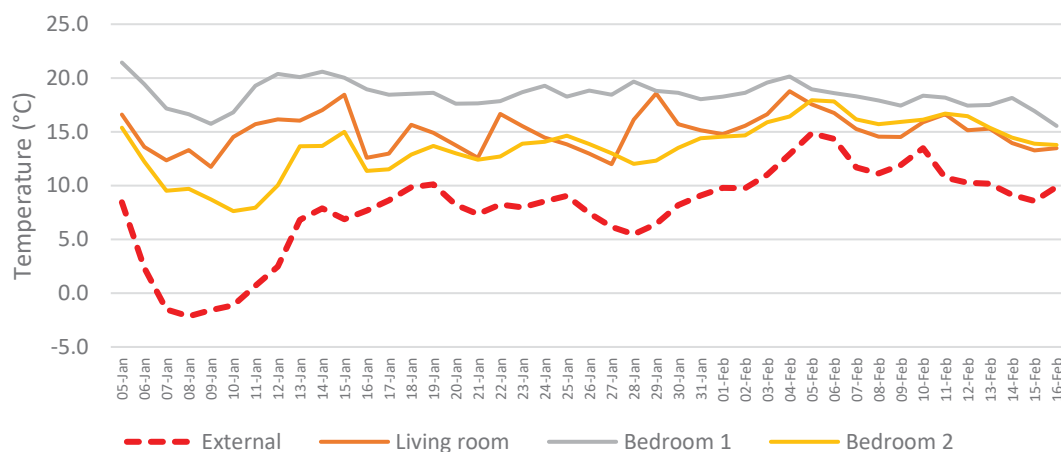


Figure 5: Mean daily temperatures in winter

Table 5: Descriptive statistics of indoor and external daily mean temperatures in summer

	Mean (°C)	Maximum (°C)	Minimum (°C)	Percentile 25 (°C)	Percentile 75 (°C)	St. Dev
External	7.85	14.90	-2.10	6.80	10.20	4.16
Living room	15.06	18.80	11.70	13.60	16.20	1.77
Bedroom 1	18.45	21.40	15.50	17.70	19.30	1.22
Bedroom 2	13.59	17.90	7.60	12.30	15.40	2.49

Looking at the hourly temperature profiles in Figure 6, it is discovered that temperatures in the living room and bedroom 2 are affected by the occupancy, meaning that they are higher when the house is fully occupied. The temperature profile in these two spaces have two peaks, one in the morning and the other in the evening. Bedroom 1 has had higher temperatures during the day and evening, indicating the use of the room throughout the day.

Notwithstanding that the heating has been on most of the time, temperatures below the recommended ones (22-23°C) have occurred for over 95% of the occupied hours in all the rooms.

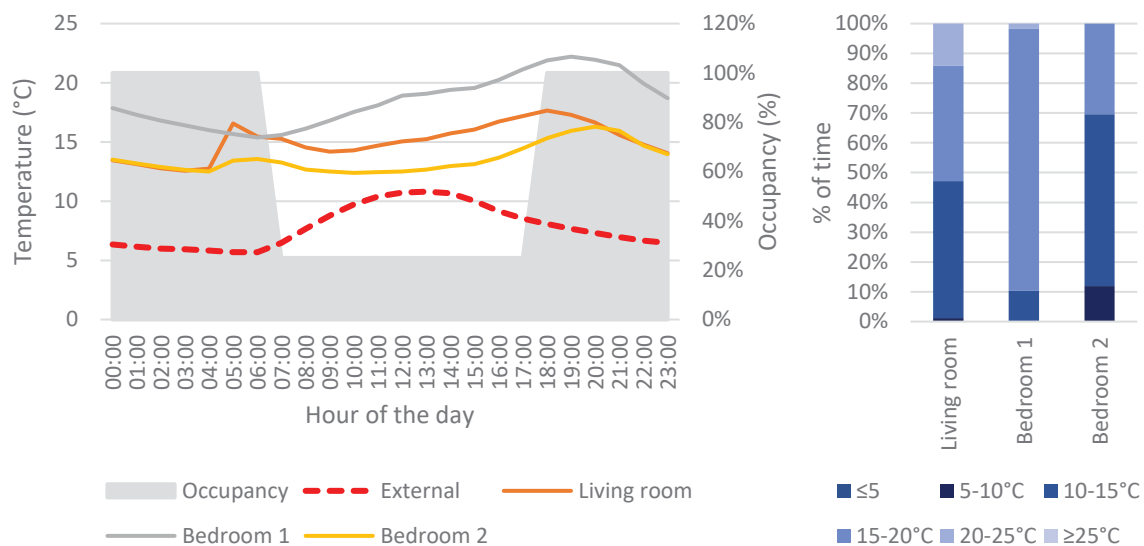


Figure 6: Mean temperatures during the day

The occupant completing the questionnaire was feeling cold and wanted to be much warmer, in an indoor temperature of 16.4°C.

### Energy behaviours in summer and winter

An investigation of the occupants' behaviour during the summer and winter was also undertaken and the main results are given in Table 6 for summer and winter respectively. The occupants did not think much about energy and how it is used. They used to open windows and doors most of the time when heating or cooling was on during the day. Furthermore, they used a very high heating setpoint in winter and a very low cooling setpoint in summer.

Table 6: Occupants' behaviours during the summer and winter

	Cooling	Heating
Cooling/heating on during the year	June-September	November-May
Cooling/heating on during the day	All day	All day
Cooling/heating on during the night	Yes	Yes
Control of room temperature	Never gets cold. It is always too hot. Always select a lower setpoint temperature when it gets too hot. The setpoint the used the most was 16°C.	They used a setpoint of 30°C all the time, and when it gets too hot they open the windows. In the bedroom they used the sleep-mode option in their inverter air conditioning device
Window operation during the day	Open most of the day	Very often during the day
Opening windows when cooling/heating is on	Yes	Yes

Heating and cooling were performed for seven and four months of the year respectively and the house was heated and cooled during the day and night. However, they found the house to be hot in summer and cold in winter, and the main reason for that is the careless operation of windows and doors.

They never opened the windows during the night in summer because of safety issues, while there was a cultural issue in this family regarding to hospitality. A carpet was placed that prevented closing the door (Figure 7).

*“...it is not nice to close the front door.....this would show people they are not welcomed...”*

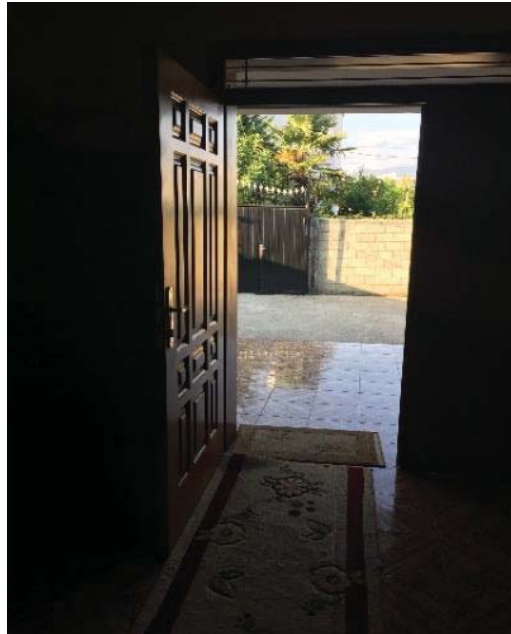


Figure 7: The use of carpet to prevent closing the door

Because there is a localised (by room) heating/cooling solution in most of Albanian houses, generally it is treated only the living room and one of the bedrooms, and occupants tend to stay all in the same room to save energy. However, in this household, all the rooms are heated/cooled. Bedroom 1 that was heated and cooled all the time, was used as a study room by the daughter of the homeowner, preparing for the exams. However, this was not the only period when all the rooms were occupied:

*“...my daughter is using more energy than all of us together...”*

*“...but exams are not the only reason. Both of my children tend to spend lots of time in their bedrooms when they are home...”*

Notwithstanding they claimed not to have enough information on how to save energy, they were feeling powerless to change habits and to be consistent on what they knew was wasting their energy in their home.

## Conclusion

An analysis of the energy and thermal conditions, as well as occupants' energy behaviours of a case study bungalow in Tirana was undertaken in this paper using data collected through two field studies conducted in June-August 2016 and January-February 2017, to cover the cooling and heating season respectively in Albanian climate. In-sight of energy consumption together with thermal comfort were given for both seasons, as well as an examination of the



human behaviour effect in achieving the adequate comfort. It was revealed that the house had an annual energy consumption nearly 35% higher than the average energy consumption in Albanian households. Very low indoor temperatures in winter and very high ones in summer, associated with a high variation throughout the day has been the product of not only the building's properties, but occupants' behaviours in particular. Consistency in energy behaviours is found to be key that is missing in achieving an acceptable and comfortable environment in the house. On the other hand, it reveals that windows and doors operation might not be a result of misinformation or lack of knowledge in their effect in energy performance of the house, but it could be because of social and cultural norms. They might have been underestimated.

The research also approves the fact that other studies have shown, that successful buildings are those where occupants are well-informed, either intuitively or by their management and insufficient understanding, as well as poor maintenance can contribute towards energy use exceeding expectations (Bordass et al., 1994).

These preliminary findings substantiate the need to consider occupants' behaviours and their willingness to change their behaviours before selecting any retrofitting strategies, so that the estimated energy savings and thermal comfort are reachable. That is why treating each household as in-depth case study (Gupta and Barnfield, 2013; Tweed, 2013; Ingle et al., 2014) and proposing the solution specifically for them, is needed to understand the people who live in the properties.

## References

- Bartiaux, F., et al. (2014) 'A practice–theory approach to homeowners' energy retrofits in four European areas', *Building Research & Information*, 42(4), pp. 525-538. doi: 10.1080/09613218.2014.900253.
- Bordass, B., et al. 'Daylight use in open-plan offices: the opportunities and the fantasies'. *CIBSE Lighting Conference*. Cambridge, 1-11.
- BPIE (2011) 'Europe's buildings under the microscope: A country-by-country review of the energy performance of buildings'. Brussels: Buildings Performance Institute Europe (BPIE). Available at: [http://bpie.eu/wp-content/uploads/2015/10/HR\\_EU\\_B\\_under\\_microscope\\_study.pdf](http://bpie.eu/wp-content/uploads/2015/10/HR_EU_B_under_microscope_study.pdf).
- Churchill, W. (1943) 'Churchill and the Commons Chamber', Available at: <http://www.parliament.uk/about/living-heritage/building/palace/architecture/palacestructure/churchill/> (Accessed 15.09.2016)
- Crosbie, T. and Baker, K. (2010) 'Energy-efficiency interventions in housing: learning from the inhabitants', *Building Research & Information*, 38(1), pp. 70-79. doi: 10.1080/09613210903279326.
- Darby, S. (2010) 'Smart metering: what potential for householder engagement?', *Building Research & Information*, 38(5), pp. 442-457. doi: 10.1080/09613218.2010.492660.
- EEA (2011) 'GHG emissions from energy: (Report Number 19/2011)'. Copenhagen: EEA.
- Energy Community 2011. Synthesis of the assessment of Contracting Parties' Energy Efficiency Action Plans as required by the Energy Community Ministerial Council Decision D/2009/05/MC-EnC of 18 December 2009 on the implementation of certain Directives on Energy Efficiency.
- Energy Community (2015) 'Albania: Energy efficiency facts and figures', Available at: [https://www.energy-community.org/portal/page/portal/ENC\\_HOME/MEMBERS/PARTIES/ALBANIA](https://www.energy-community.org/portal/page/portal/ENC_HOME/MEMBERS/PARTIES/ALBANIA)
- European Commission (2016) 'Global action: Albania INDC', Available at: [http://www4.unfccc.int/submissions/INDC/Published%20Documents/Albania/1/Albania\\_INDC\\_submission%20\(1\).pdf](http://www4.unfccc.int/submissions/INDC/Published%20Documents/Albania/1/Albania_INDC_submission%20(1).pdf)
- Global Buildings Performance Network (2015) 'Deep Building Renovation: International Policy Guidelines'. Paris, France. Available at: [http://www.gbpn.org/sites/default/files/6.DR%20IntPolGuidel\\_Cover\\_Report.pdf](http://www.gbpn.org/sites/default/files/6.DR%20IntPolGuidel_Cover_Report.pdf).
- Gram-Hanssen, K. (2010) 'Residential heat comfort practices: understanding users', *Building Research & Information*, 38(2), pp. 175-186. doi: 10.1080/09613210903541527.
- Gram-Hanssen, K. (2013) 'Efficient technologies or user behaviour, which is the more important when reducing households' energy consumption?', *Energy Efficiency*, 6(3), pp. 447-457. doi: 10.1007/s12053-012-9184-4.

- Guerra-Santin, O., *et al.* (2016) 'Mixed methods approach to determine occupants' behaviour – Analysis of two case studies', *Energy and Buildings*, 130, pp. 546-566. doi: <http://dx.doi.org/10.1016/j.enbuild.2016.08.084>.
- Gupta, R. and Barnfield, L. (2013) 'Unravelling the unintended consequences of home energy improvements', *Sustainable Building Conference 2013*. Coventry University, pp.
- Gupta, R., Barnfield, L. and Hipwood, T. (2014) 'Impacts of community-led energy retrofitting of owner-occupied dwellings', *Building Research & Information*, 42(4), pp. 446-461. doi: 10.1080/09613218.2014.894742.
- Gupta, R. and Chandiwalla, S. (2010) 'Understanding occupants: feedback techniques for large-scale low-carbon domestic refurbishments', *Building Research & Information*, 38(5), pp. 530-548. doi: 10.1080/09613218.2010.495216.
- Gupta, R., *et al.* (2015) 'Intent and outcomes from the Retrofit for the Future programme: key lessons', *Building Research & Information*, 43(4), pp. 435-451. doi: 10.1080/09613218.2015.1024042.
- IEA (2013) 'World Energy Outlook 2012: Executive Summary'. Available at: <http://www.iea.org/publications/freepublications/publication/English.pdf>.
- Ingle, A., *et al.* (2014) 'Better home energy audit modelling: incorporating inhabitant behaviours', *Building Research & Information*, 42(4), pp. 409-421. doi: 10.1080/09613218.2014.890776.
- Instat (2012) 'Population and housing census 2011'. Tirana: Insituti i Statistikes. Available at: [http://www.instat.gov.al/media/177354/main\\_results\\_population\\_and\\_housing\\_census\\_2011.pdf](http://www.instat.gov.al/media/177354/main_results_population_and_housing_census_2011.pdf) (Accessed: 10/10/2015).
- International Energy Agency (2008) 'Energy in the Western Balkans: The path to reform and reconstruction'. Paris: IEA. Available at: <http://www.iea.org/publications/freepublications/publication/Balkans2008.pdf>.
- IPCC (2014) '5th Assessment Report-Climate Change 2014: Mitigation of Climate Change'. Available at: <https://www.ipcc.ch/report/ar5/>.
- Janda, K. B. (2011) 'Buildings don't use energy: people do', *Architectural Science Review*, 54(1), pp. 15-22. doi: 10.3763/asre.2009.0050.
- Janda, K. B. and Topouzi, M. (2015) 'Telling tales: using stories to remake energy policy', *Building Research & Information*, 43(4), pp. 516-533. doi: 10.1080/09613218.2015.1020217.
- Karvonen, A. (2013) 'Towards systemic domestic retrofit: a social practices approach', *Building Research & Information*, 41(5), pp. 563-574. doi: 10.1080/09613218.2013.805298.
- Shehi, T., Gjoka, K. and Schweizer, R. (2011) 'Udhëzues praktik për të arritur eficiencën termike në ndërtesat e banimit'. Tirana: Co-PLAN,. Available at: [https://issuu.com/co-plan/docs/2011\\_ritja\\_e\\_efiencences\\_termike\\_ne\\_4](https://issuu.com/co-plan/docs/2011_ritja_e_efiencences_termike_ne_4).
- Shove, E., Pantzar, M. and Watson, M. (2012) *The dynamics of social practice: Everyday life and how it changes*. Available at: <http://sk.sagepub.com/books/the-dynamics-of-social-practice> (Downloaded: 2016/10/12).
- Stephenson, J., *et al.* (2010) 'Energy cultures: A framework for understanding energy behaviours', *Energy Policy*, 38(10), pp. 6120-6129. doi: <http://dx.doi.org/10.1016/j.enpol.2010.05.069>.
- Tweed, C. (2013) 'Socio-technical issues in dwelling retrofit', *Building Research & Information*, 41(5), pp. 551-562. doi: 10.1080/09613218.2013.815047.
- United Nations Human Rights (2015) 'Contribution from the Republic of Albania to the OHCHR analytical study in implementing Resolution 7/23 of the Human Rights Council', Available at: <http://www.ohchr.org/Documents/Issues/ClimateChange/Submissions/Albania.pdf>
- Vlasova, L. and Gram-Hanssen, K. (2014) 'Incorporating inhabitants' everyday practices into domestic retrofits', *Building Research & Information*, 42(4), pp. 512-524. doi: 10.1080/09613218.2014.907682.
- Wingfield, J., *et al.* (2011) 'Elm Tree Mews Field Trial – Evaluation and Monitoring of Dwellings Performance: Final Technical Report'. York: Centre for the Built Environment. Available at: <http://www.leedsbeckett.ac.uk/as/cebe/projects/elmtree/>.

# Biomimicry as A Design Guide Towards Sustainable Built Environments

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**Abstract:** Built environments have great negative impacts on the environment, which further increase as the urban population grows (UNFPA 2007). Efforts have been made in the past few decades to shift towards sustainable urban development, such as aiming for zero environmental impact or 'neutral' buildings in terms of energy, water, carbon or waste. Although these targets are valuable, they are not enough. Research suggests that even if all GHG emissions were stopped at once, the slow Earth's response would mean that the effects caused by past emissions would still be experienced (IPCC, 2007). This implies that the built environment needs to have net positive environmental benefits to remediate the environmental damage rather than just sustaining the current status. Architects, urban designers and planners should explore novel ideas that could lead to such a shift in the way we design our cities.

This paper investigates Biomimicry, where nature's organisms, processes or ecosystems are mimicked in design, and its potential to present a new approach for designing the built environments to be truly sustainable or regenerative. It is important to note that biomimicry is not about the mere copying of nature's shapes, but rather the ideas, functions and principles that lie behind them. The question put forward is: how can mimicking nature be useful in finding a new methodology to design sustainable built environments?

A brief introduction to the definition, levels and principles of biomimicry is followed by the analysis and critique of international biomimetic case studies with the aim of deducing a design framework that could form the basis of a new methodology to design sustainable built environments. It is argued that the incorporation of biomimetic ideas in the design of our cities would lead to creating built environments that are positively integrated into nature rather than dominating over it.

**Keywords:** Biomimicry, Sustainability, Built Environment, Resource Efficiency.

## Introduction

Throughout history, Man has looked to nature as a source of inspiration to find solutions to the challenges he faces. It was not until the modern age and the industrial revolution that the mindset of mankind was deviated away to compete with nature rather than to live in harmony with it. Advances in technologies, together with the discovery of fossil fuels and the invention of the steam engine made way for concepts such as mass production and 'heat, beat and treat'. These concepts not only ignored the fact that resources on Earth are limited, but also, were harming the environment to the extent that threatens our own existence.

Ozone depletion, global warming and rising sea levels were all alarms that an action needs to be taken soon before the damage is beyond repair. Concepts of sustainability began to emerge to reduce the negative impacts on the environment. However, it still lacks the desired impact. One reason is that these concepts have their roots back from the industrial age. Research suggests that these actions are not enough and that there needs to be a shift in the way we think to achieve true sustainability or regenerative sustainability, which does not only try to reduce impact, but instead aims to repair and have a net positive impact on the environment.

This Paper investigates Biomimicry as a new methodology, a new way of thinking to find solutions to achieve sustainability in built environments. It presents an alternative to

the current model once described by Le Corbusier, where he said that “Buildings are machines to live in”. This paper introduces nature as the design model to look up to if we are to live in harmony with our natural surrounding instead of dominating it.

### **Biomimicry Definitions**

Biomimicry is from the Greek words ‘bios’, meaning ‘life’, and ‘mimesis’, meaning to ‘imitate’. Many researchers defined Biomimicry. The first of whom is Benyus, a biologist and a writer who founded the biomimicry movement, she defines it as “a new discipline that studies nature's best ideas and then imitates these designs and processes to solve human problems” (Benyus, 1997).

While that definition links biomimicry to design in general, Guber defined Biomimicry as “the study of overlapping fields of biology and architecture that show innovative potential for architectural problems” (Bar-Cohen Y., 2005).

Pederson Zari notes that there is no clear definition of biomimicry that architects could apply in designing their projects and therefore it is best to focus on analysing the different approaches to Biomimicry to come out with best methods to apply Biomimicry for maximum benefit (Zari, 2007).

The application of biomimicry to a design problem is the answer to the question: ‘How would nature solve this design problem?’

### **Biomimicry Levels**

When applying Biomimicry to tackle a design problem, it is vital to decide what level of biomimicry is used; that is what aspect biology is to be mimicked. According to Benyus these categories / levels are **form**, **process**, and **ecosystem** (Steadman 2008). However, Zari introduces a different classification. After analysing existing biomimetic examples, Zari broke down biomimicry into three levels; **organism**, **behaviour**, and **ecosystem** (Webb, 2005). Zari introduces a framework which suggests five further dimensions within each of these levels (Zari, 2007). It is noticed that both researchers agreed on the ecosystem level, while they differed over the other two levels. This paper adopts Zari’s classification seen as more applicable to architectural fields. A brief description of each level is given below:

#### ***Organism level***

This level includes mimicking the whole or part of a specific living organism such as an animal or a plant. An example is the Sto’s Lotusan Paint which was designed after the nanostructure properties of the Lotus leaves. The hydrophobic paint is self-cleaning as droplets of water run over its surface removing dirt particles in a similar way to the self-cleaning lotus leaves.

#### ***Behaviour level***

This level includes mimicking the behaviour of an organism or how it relates to its surroundings. An example is the East-gate building which mimics the method termites use to ventilate their nests. This example is analysed later in further detail.

#### ***Ecosystem level***

This is considered the most difficult level of mimicry, since it involves mimicry of a whole ecosystem and the complex relationships between its components and the aspects that enable an ecosystem to function efficiently (Aziz & El sherif, 2015). An example is the self-

watering Pikaplant product, where a plant specimen is sealed in a humid jar biotope. The plant never needs watering, since it recycles and reuses the water in the jar in a similar way to the water cycle in nature.

Kibert (2006) suggests that the complexity in understanding ecosystems makes it impossible for designers to engage modelling ecosystems in their work, since, according to Kibert, human designs are non-complex. However, Zari (2010) argues otherwise. Zari defends that the ever increasing knowledge about nature would enable us to mimic the complex relationships in ecosystems to increase the sustainability of our Built Environments (Pedersen Zari, 2010).

There could be overlaps between the different levels of biomimicry as would be evident in one of the case studies handled in this paper. For instance, a number of systems that relate to each other like an ecosystem is an ecosystem level biomimicry. At the same time the components of those systems may be modelled after organisms or their behaviour in a similar way that a forest ecosystem is home to many interrelated organisms (Zari, 2006).

### **Nature's Design Principles**

The previous section explains how designers could relate to nature, but do not necessarily illustrate what nature is. In her book, Benyus has identified nine statements to be the principles, laws or strategies that nature follows in its designs (Benyus, 1997). The biomimicry institute refined those laws to be ten design principles that are evident in nature's design (Biomimicry Institute, 2015). It is argued that the application of these principles in human designs would make these designs biomimetic and as much sustainable as nature's designs are. That is, they behave in a similar way to nature's designs. These ten principles are defined as follows:

**Principle 1:** Nature uses only the energy it needs and relies on freely available energy

**Principle 2:** Nature recycles all materials (finds use for all waste)

**Principle 3:** Nature is resilient to disturbances (the ability to recover after sudden changes)

**Principle 4:** Nature optimizes rather than maximizes (no excessive use of material or energy)

**Principle 5:** Nature rewards cooperation (between organisms and / or their context)

**Principle 6:** Nature runs on information (to be able to respond to their environment)

**Principle 7:** Nature uses chemistry and materials that are safe for living beings

**Principle 8:** Nature builds using abundant resources, incorporating rare resources only sparingly

**Principle 9:** Nature is locally attuned and responsive

**Principle 10:** Nature uses shape to determine functionality (form follows function)

So, if we want to look to nature as a design model, we probably need to fulfil as much of these principles in our designs as possible. Fulfilling these principles would result in design that function in a similar way as nature and thus would be as sustainable. The case studies in the following section will be analysed in comparison to these ten principles.

### **Application of Biomimicry in the Built Environment**

This section analyses different international case studies with the aim to identify which level of biomimicry is the most suitable for achieving sustainable built environments that function like nature's designs. The design challenge, the natural model used, the biomimicry level and nature's design principles achieved in each case study are identified. The degree of fulfilment of the ten design principles identified earlier is regarded as an indication to how much a design is able to mimic nature to the best degree possible and therefore is as sustainable.



### Case Study 1: East-Gate Center, Harare, Zimbabwe

A frequently cited example of behavioural level biomimicry in architecture is East-Gate Center by Mick Pearce (Shown in Figure 1).



Figure 1: Exterior facade of East-Gate Center, Zimbabwe. Source: archnet.org

*Mimicry level* : Behavioural level

*Challenge* : Passive Ventilation of a large structure to achieve thermal comfort

*Natural model* : Termite mound

*Analogy between termite mound and East-Gate building:*

The architect examined the nest's natural ventilation system to come up passive techniques to regulate indoor temperatures and passively ventilate the building to maintain the interior environment within comfort levels (Kowaltowski et al. 2010).

The termite mounds protect the nest and royal chambers and the combs containing fungus which is their main source of food. Although the outside temperatures fluctuate widely between 2 and 40 degrees Celsius, the termites manage to maintain a thermally stable environment kept within a range between 30 and 32 degrees Celsius, which is perfect for this fungus growth (Klein 2009).

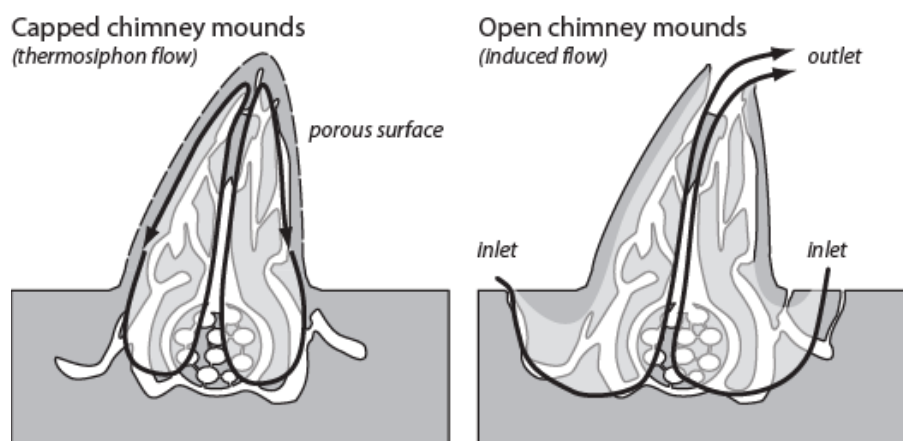


Figure 2: Termite mound models with capped and open chimneys. Source: [www.projects.science.uu.nl](http://www.projects.science.uu.nl)



Termites build a network of perfectly located vents that induce air flow through convection currents. Air flows through enclosed underground vents with muddy walls which cause them to cool down. As shown in Figure 2, cooled air enters the mound at the bottom of the mound. Then air is channelled as it warms to the peak of the mound where exits through chimneys. Surprisingly, termites open or plug these vents to maintain the required conditions. Termites constantly build new vents and plug old inefficient vents.

This behaviour inspired the architect's design. As shown in Figure 3, the design consists of exterior buildings with a glass center connecting them. First, similar to mud, he used concrete, which has a high thermal mass and is available locally. The external air is channelled through the building mass where it is passively cooled or warmed depending on the temperature of the building mass. The conditioned air passes through the building floors, from where it is pulled by chimneys (seen in Figure 1) using stack effect (Maglic 2014).

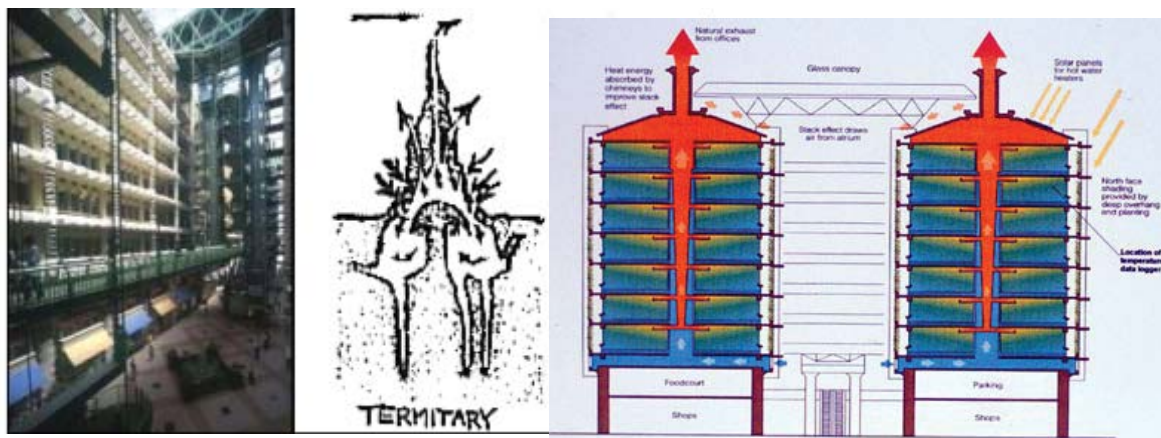


Figure 3: a. East-gate building, b. Ant nest, c. Ventilation System. Source: [www.archnet.org/](http://www.archnet.org/)

The result was a reduction in energy consumption of up to 52% in comparison with conventional buildings of the same size in Harare, Zimbabwe (Smith, 1997; Baird, 2001).

However, there are limitations to the design. While the building is successful in terms of thermal stability, thorough analysis of the termite mounds explains that, to regulate temperatures there are complex interactions with surrounding environments than was thought at the time of the design. This suggests that a more in-depth analogy could lead to higher benefits in terms of energy consumption (and thus GHG emissions) and help in creating 'living' buildings that mimic the termites mound with a deeper understanding. (Turner and Soar, 2008)

The following Table 1, represents an analysis to this case study and how much it fulfills the ten design principles explained in the previous section. The degree of fulfillment of these principles is considered a measure of how much a design is behaving in a similar way to nature and therefore should be as sustainable. A principle is either fulfilled (Y), Not fulfilled (N) or Partially fulfilled (P).

Table 1. Nature's Design Principles Fulfilment-Case study 1, Source: Author

Nature's Design Principles	Fulfilled (Y/N/P)	Notes
Principle 1	P	50% reduction in energy consumption
Principle 2	N	Not made of recycled materials
Principle 3	N	Not resilient to disturbances
Principle 4	P	Only ventilation was tackled using passive methods
Principle 5	N	
Principle 6	N	
Principle 7	N	Requires deeper analysis of used materials
Principle 8	Y	Use of locally available materials eg. Concrete
Principle 9	Y	Adaptive ventilation system inspired by local organism
Principle 10	N	Requires deeper analysis

A few principles have been fulfilled or partially fulfilled which indicates that there is still room for improvement in the design methodology to reach better results.

### **Case Study 2: Biomimetic Office Building, Zurich, Switzerland**

Unlike East-gate building, which was classified as biomimetic only after completion, the Biomimetic Office building, shown in Figure 4 is the first building to be designed comprehensively with biomimicry in mind from the very first design steps. The architecture firm, Exploration Architecture, aimed to design a class leading environmental office building by incorporating several biomimetic features.



Figure 4: The Biomimetic Office, Zurich, Switzerland. Source: <http://i.vimeocdn.com>

*Mimicry level* : Organism and Behavioural levels

*Challenge* : Daylighting, structure, shading and material efficiency

*Natural models* : A number of models including spook fish, brittle star, stone plant, cuttlefish bone, birds' skull structure, termites, beetle wings, mimosa leaves

*Analogy between natural models and the inspired design:*

The building was designed to maximize the environmental performance, while making use of local materials and climate. Daylighting was the driving force that shaped the building form in such a way that daylight could reach all floor areas. The design team looked to several examples in nature for inspiration on how to enhance the use of daylight:

- The Spook fish which lives in water with low level of daylight use a mirror structure in its eyes which focuses low-level bioluminescence onto its retina as shown in Figure 5. This inspired the design of a reflective structure in the middle of the building's atrium to reflect light back into the darkest parts of the building's floor slabs as in Figure 7.

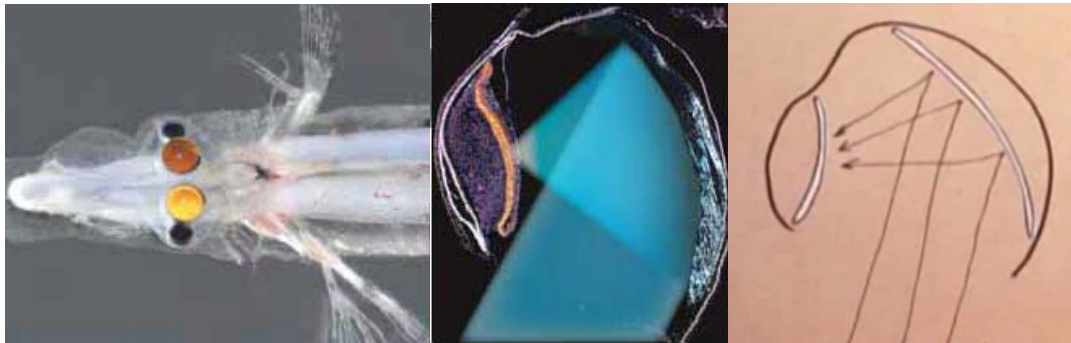


Figure 5: Spook fish eye structure. Source: <http://i.vimeocdn.com>

- The brittle-star is a star fish living 500m below the ocean, where light levels are minimum. It has developed optically perfect lenses that collect and focus light onto its receptors for early prediction of predators as seen in Figure 6. This has inspired the design of a canopy covering the atrium that directs light into the atrium and onto the reflective mirrors.

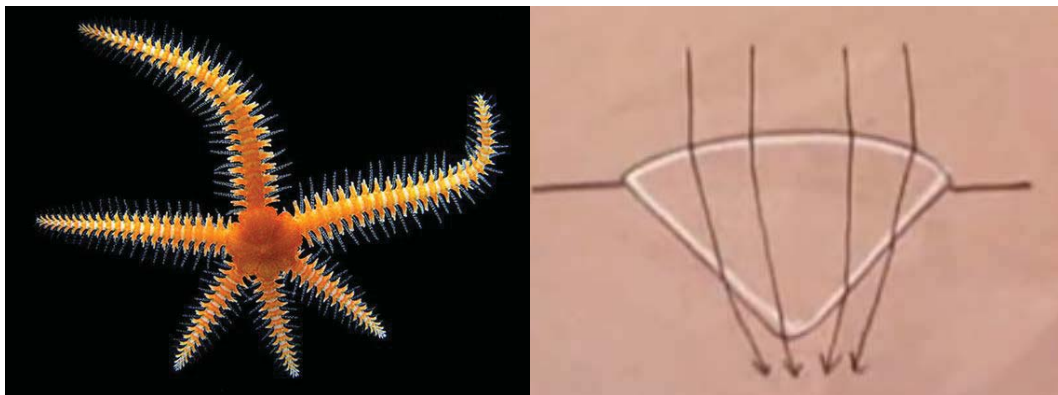


Figure 6: Brittle Star fish and the structure of its light receptors. Source: <http://i.vimeocdn.com>

From the mechanism of the spook fish eye and the brittle star cell structure, Pawlyn designed a canopy that focuses light into the building and a reflective surface in the courtyard to reflect day light to the areas which otherwise be in shade.

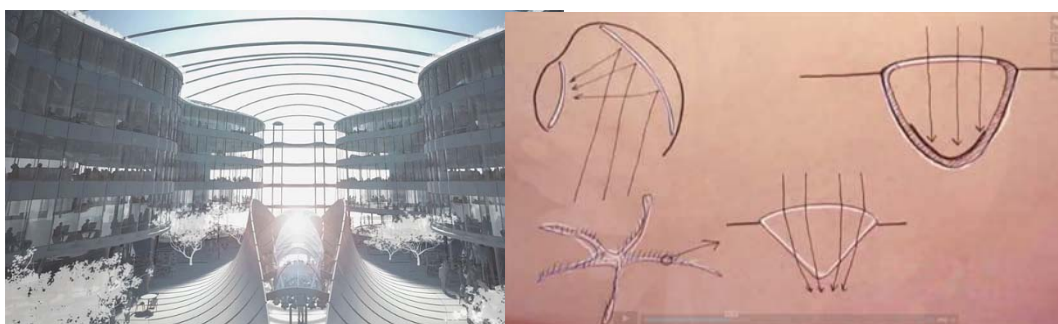


Figure 7: Designed atrium and architect's concept sketches. Source: <http://i.vimeocdn.com>



Another important aspect of the design is the building's structure system. The design team aimed at reducing the use of materials without compromising structural strength. Again, they turned to nature for design models:

- Birds skulls and the cuttlefish bone, both efficiently place material to the parts where they only needed as illustrated in Figure 8. Therefore, material is reduced, while creating a very rigid structure with very thin walls at the top and the bottom.

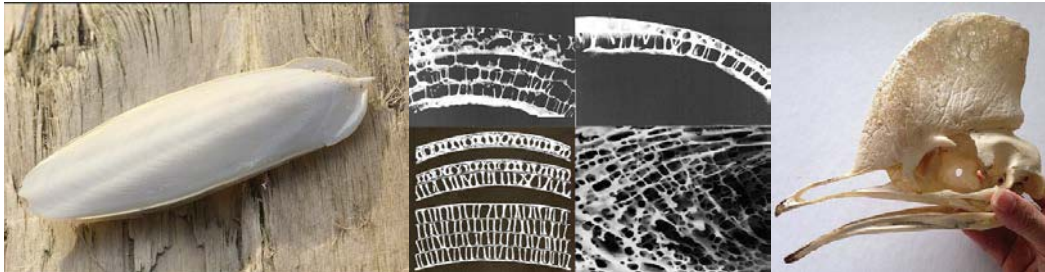


Figure 8: Cuttlefish bone and birds' skull structure. Source: biomimetic-architecture.com

After a structure loads analysis, the floor slabs and columns were consequently designed in such a manner that concrete is allocated only where there are forces and excluded where they are not useful as shown in Figure 9. This allowed certain structure elements to be hollow where they can accommodate wiring or ventilation elements.

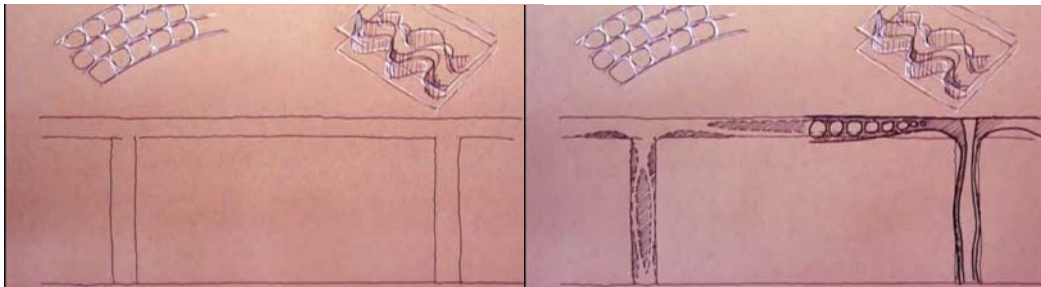


Figure 9: Architect's concept sketches showing conventional vs design structure elements. Source: <http://i.vimeocdn.com>

Other natural models that were used include termites for passive cooling, beetle wings and mimosa leaves for a shading system that allows only adequate amount of light. When completed, it is to be one of the world's leading low energy office buildings.

However, there are limitations to the design. While the design addressed the issues of resource efficiency, structure, daylighting and energy efficiency; it lacked the higher level of biomimicry (ecosystem level). Of course, this is difficult to apply on a building level and would require a larger scale to be applicable. However, on the building scale, there could have been an understanding of how this building would interact with the surrounding context whether other buildings or local environment. This could have brought a deeper level of biomimicry opening the gates to maximum sustainability potential.

Table 2. Nature's Design Principles Fulfilment- Case study 2, Source: Author

Nature's Design Principles	Fulfilled (Y/N/P)	Notes
Principle 1	Y	To be one of the world's lowest energy office buildings
Principle 2	N	Not made of recycled materials
Principle 3	N	Not resilient to disturbances
Principle 4	Y	Significant Reduction in construction and envelope materials
Principle 5	N	
Principle 6	Y	Adaptive shading system responds to lighting level information
Principle 7	P	Requires deeper analysis of used materials
Principle 8	Y	Use of locally available materials
Principle 9	Y	Responds to local climate
Principle 10	Y	Form was driven by daylighting constraints

In comparison with table 1, it is evident from Table 2 that when both levels of biomimicry (organism and behavioral) were included in the design process in its initial stages more design principles of nature were covered. This design has the potential to be more sustainable than the previous case study.

However, some principles require application of biomimicry on a larger scale to be applicable. For instance, Principle 5, *nature rewards cooperation*, need to be applied on interrelations between different buildings that are the building blocks of the larger scale urban context. This shall be examined in the next case study.

### **Case Study 3: District Rieselfeld, Freiburg, Germany**

The Previous two examples were architectural. Even though, the second case study included biomimicry since the initial design stages, it still experiences limitations in terms of sustainability. This case study explores ecosystem level biomimicry and how it could be more useful to design on an urban level rather than designing individual buildings.

District Rieselfeld in Freiburg, Germany (Figure 10) was planned in 1992 with aim to contain mixed-use high-density buildings (Figure 11) with courtyards in between along with recycling points and open play areas. It features cycling paths and non-vehicle friendly streets. On-site water management ensures collection and reuse of storm water (Spiegelhalter & Arch 2010).



Figure 10: Aerial view of district Rieselfeld. Source: Google Earth

*Mimicry level* : Ecosystem level

*Challenge* : A district that is solar powered and recycles water and waste

*Natural models* : Trees, water cycle and nutrients cycle (ecosystem level models)

*Analogy between natural models and the inspired design:*

Water cycle in nature inspired the storm water management techniques in the district such as onsite storm water collection in underground tanks in a similar way that water is infiltrated and stored in underground water tables.

Nature uses only the energy it needs and runs on freely available energy. This inspired planners to determine energy targets for the buildings in the district such that they could be covered by renewable energy sources. This would force building to apply building envelopes of increased efficiency. Subsidies are granted on the use of PV cells, passive and active solar thermal heating and cooling.

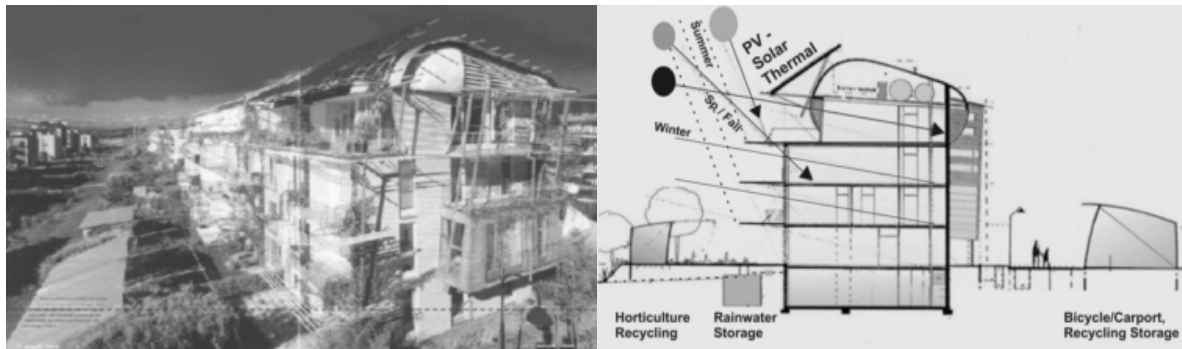


Figure 11: Solar-powered low-energy town-houses of Rieselfeld. Image: Thomas Spiegelhalter

Nutrients cycle inspired the reuse of waste produced from households and saw mills' waste dust to fuel the heat and power plant. Biogas is produced from landfills and is used to power the district-heating system. The biogas could be also used for public transport. Other design aspects to reduce the carbon foot print include traffic calmed streets where no vehicles are allowed, to encourage pedestrian and cycling movement.

This resulted in a balanced circular metabolism that uses renewable energy as the primary power source and recycles waste into an energy source.

Table 3: Nature's Design Principles Fulfilment- Case study 3, Source: Author

Nature's Design Principles	Fulfilled (Y/N/P)	Notes
Principle 1	Y	All town houses are solar powered + biogas district heating
Principle 2	Y	Recycles waste to productive energy source
Principle 3	N	Not tested
Principle 4	Y	No excessive use of energy or materials
Principle 5	Y	Beneficial relationships between neighbourhood elements
Principle 6	Y	Adaptive shading system responds to lighting level information
Principle 7	P	Requires deeper analysis of used materials
Principle 8	Y	Use of locally available materials
Principle 9	Y	Responds to local climate
Principle 10	Y	Form was designed to reduce heat gains/losses



In comparison with previous tables, it is clear from Table 3 that when a higher level of biomimicry (ecosystem biomimicry) was applied on the larger scale (urban scale rather than the architectural scale) almost all design principles of nature were covered. This design methodology has the most potential of all studied case studies to be more sustainable.

However, the district was designed before the biomimicry movement by Benyus and therefore was not designed with biomimicry on the design table from day 1. In the author's opinion that the incorporation of biomimicry (especially ecosystem level biomimicry) in urban design from the initial design stages would have the most potential to create cities that function in a similar way to nature and are therefore as sustainable.

## Conclusion

Mankind need to rethink the way they build things in order to achieve a truly sustainable future. Novel ideas need to be explored and tested. The current building design model has failed to ensure a sustainable building trend. A new design model is needed to shift towards a sustainable future. Nature presents a very good potential, since it has sustained itself through billions of years and has developed time-tested strategies that secured its continuum till today.

Biomimicry, the science of imitating natural models presents a good potential when integrated into the design of the built environment. Through the analysis of the above case-studies it was shown that buildings that were designed with biomimicry in mind as a guide throughout the design process present a more promising example than those buildings that were classified as biomimetic after being built. Different levels of biomimicry prove to be more promising than others. Ecosystem level biomimicry gives a more holistic approach to design of built environments. If applied on an urban planning and design level it would give the opportunity of designing cities that behave like forests and that are sustainable.

The more principles the design of the built environment accomplishes, the more likely the design would behave as nature's designs. The genius of place and responsiveness to local environment is very important to set design goals in terms of energy, water and carbon budgets for a given design such that they behave as local ecosystems behave.

Further studies could test how could all levels of biomimicry be applied in a built environment from the largest scale of planning to the very specific detail or architectural element. Biomimicry application in that manner could have even higher potential than the case studies examined in this paper as Benyus suggests that "a full emulation of nature engages at least three levels of mimicry: form, process, and ecosystem".

## References

Aziz, M.S. & El sherif, A.Y., 2015. Biomimicry as an approach for bio-inspired structure with the aid of computation. *Alexandria Engineering Journal*, 55(1), pp.707–714. Available at: <http://dx.doi.org/10.1016/j.aej.2015.10.015>.

Baird, G., 2001, *The Architectural Expression of Environmental Control Systems*, London and New York, NY, Spon Press.

Bar-Cohen Y., 2005 (Ed.), "Biomimetics: Mimicking and being Inspired by Biology," CRC Press, pp. 505

Benyus, J.M., 1997. *Biomimicry: Innovation Inspired by Nature*. Perennial (Harper Collins.)

Biomimicry Institute, 2015. *Nature's Unifying Patterns*. Biomimicry Toolbox, pp.0–2.

Kibert, C.J., 2006, 'Revisiting and reorienting ecological design', Paper presented at the Construction Ecology Symposium, Massachusetts Institute of Technology, Cambridge, MA.

Klein, L., 2009. A phenomenological interpretation of biomimicry and its potential value for sustainable design. , p.106.

Kowaltowski, D.C.C.K., Bianchi, G. & De Paiva, V.T., 2010. Methods that may stimulate creativity and their use in architectural design education. *International Journal of Technology and Design Education*, 20(4), pp.453–476.

Maglic, M.J., 2014. Biomimicry: Using Nature as a Model for Design. , (February), pp.1–88.

Pedersen Zari, M., 2010. Biomimetic design for climate change adaptation and mitigation. *Architectural Science Review*, 53(2), pp.172–183.

Pedersen Zari, M. & Storey, J. B. (2007) An Ecosystem Based Biomimetic Theory for a Regenerative Built Environment. Lisbon Sustainable Building Conference 07. Lisbon, Portugal.

Smith, F., 1997, 'Eastgate, Harare, Zimbabwe', *Arup Journal* 32(1), 3–8.

Spiegelhalter, T. & Arch, R.A., 2010. Biomimicry and circular metabolism for the cities of the future. *WIT Transactions on Ecology and the Environment*, 129(November 2016), pp.215–226.

Turner, J.S. and Soar, R.C., 2008, 'Beyond biomimicry: What termites can tell us about realizing the living building', Paper presented at the First International Conference on Industrialized, Intelligent Construction (I3CON).

Webb, S., 2005. The Integrated Design Process of CH2. *Environment Design Guide*. CAS 36.

Steadman, P. 2008. *The Evolution of Designs-biological Analogy in Architecture & Applied Arts*. Oxon: Routledge.

Zari, M.P., 2006. Biomimetic Approaches To Architectural Design for Increased Sustainability. *Design*, (April), p.2006.

Zari, M.P. 2007. Biomimetic Approaches to Architectural Design for Increased Sustainability. Sustainable Building Conference. Auckland.

# From Watt to How: upgrade within existing neighbourhoods

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**Abstract:** Neighbourhoods are the collective reality in which urban buildings evolved for centuries, the reason for their diversity and versatility, and the key to their perseverance. Nonetheless successive European investigations and legislation favour individualistic approaches targeting only at salvageable Watts estimations, facilitating theoretical and legislative production while hampering action and compromises results. Sustainable (re)Design requires a thorough understanding of the intertwined systems and scales, current and upcoming, to assure that Climate Change mitigation, Energy Efficiency, Energy Poverty, individual knowledge or financial (in)capabilities, to name a few, are not opposing parameters. Starting from an existing building within a UNESCO Heritage setting, documented throughout international projects and publications, the author emphasizes neighbourhood scale as a collective opportunity for action. Acknowledging that individual “deep assessments” of existing buildings (microscale) provide specific patterns that translate individual characteristics and uses, Watts included, the investigation shows that their full relevance can only be harnessed if matched with the collective goals of the neighbourhood (mesoscale) they belong to. Scale and context can help identify strategies to replicate, complementary qualities to share and space for innovative financing, contracting, deployment, operation and optimization that better match the macroscale measures defined by regional, national and international efforts. The authors demonstrate that going beyond Watt □to understand What matters to each neighbourhood scale□ is key to understand How to make such measures viable, How to make them solve other problems beyond energy efficiency and How to merge existing infrastructure and funding opportunities; while simultaneously attracting the majority of the stakeholders interest (policy makers, academia, exterior investment, owners and users) into the win-win partnerships that better match each neighbourhood.

**Keywords:** Zero and Low Carbon neighbourhoods, Energy Efficiency, Energy Deficiency, District Scale, Renewable Energy.

## Introduction

Cities evolve and adapt, slowly fighting, following and incorporating the needs of each generation, constraining while protecting: (slow) time sprays the “foam” from innovation, increasing adherence and, again, the inertia we tend to recognize and value (Brito and Gameiro da Silva, 2012). In this context rehabilitation interventions must be an opportunity to recognize the background and the relations that kept those areas as distinguishable entities, as their existing buildings and neighbourhoods, the “new” from previous decades, often fulfilled the needs and expectations of those who preceded us; while shaping our individual perspective of a collective environment, often not coincident with that of others.

Cities observed and participated in the introduction of more or less intrusive innovations in their buildings. The assimilation of grid water required supply systems that pierced buildings, created the need for wet spaces and storage tanks, and waste water recollection systems with ducts or exterior drainages, now converging into disposal areas punctuated by treatment installations. The assimilation of electricity required production facilities and conversion buildings alongside a profusion of cables, allowing for safer interior light and acclimatization, followed by other “comfort” features like radio, telephone, TV and internet, progressively protruding outside with antennas, parabolic dishes and cooling units.

The assimilated evolution in the existing buildings recalls that social-changing transformations already succeeded in significantly more constrained environments. Although these changes might now look seamless, they entail a vast knowledge that may be

of use on implementing sustainability-related actions, or even represent opportunities for new strategies. Yet not much of this potential remains visible: as building (microscale), neighbourhoods (mesoscale) and cities/regions/countries (macroscale) evolve, most of the legal frameworks, practices and even the way stakeholders relate with each other change. A small overview of some of these is necessary to contextualize the proposed reshuffle.

### ***Inclusion or exclusion: prejudice and discrimination in energy related rehabilitation***

Discrimination is defined as “1. *The unjust or prejudicial treatment of different categories of people, especially on the grounds of race, age, or sex. [but also the]* 2. *Recognition and understanding of the difference between one thing and another.*” (OD, 2017). The difference between the negative/positive views is thus related to the amount of pre-image “projected” onto the discriminated entity, and to its course or fine match. “Ageism” is a common form of discrimination in building rehabilitation as age and “wrinkles” are assumed as incapability. Using the language of an area where discrimination managed a flip, it is necessary to look “under the hood” to see what is really there: a fresh façade may hide life-threatening problems, whereas some cracks on the wall may just signal some natural movements. Adequate discrimination is necessary, in all cases. Notwithstanding, the scope of energy related rehabilitation of existing buildings is bipartite, a fact that matches prejudice, lack of knowledge and probably administrative concerns.

The EPBD-“recast” (EU, 2010) excludes from compliance “*buildings officially protected as part of a designated environment or because of their special architectural or historical merit, in so far as compliance with certain minimum energy performance requirements would unacceptably alter their character or appearance*”. These legal exclusions add up to the already existing exceptions, as buildings are not obliged to comply with succeeding regulations, except in the cases where significant works or changes of use are expected, and even in those situations entitled to extensive prerogatives. Listed buildings (Historic England, 2017; NRH, 2017) or those just located within a historic or protected area are excluded, while all the others are included. Depending on their location relatively to an invisible line, two exactly similar buildings with the same orientation are treated unequally: one stays frozen in the state it was listed at, while the other has to endure today’s’ rehabilitation strategies, even if they don’t match. In Mismatch, Inclusion and Exclusion (Brito, 2016a) it is argued that lack of knowledge and the costs of adequate building assessments might have favoured this administrative approach, and that the same simplification was applied to the majority of the built environment.

Energy security and climate change problems have been tackled with a significant investment on new buildings performance research, whereas the existing buildings retrofit merely received cloned recipes from new construction, with small “disclaimers” referring to the need to adapt wisely. The constant bet on innovation and on innovative construction solutions lead to a progressive denial of previous knowledge and their removal from scholar educational programs: nowadays the number of specialists able to act wisely in ancient buildings with traditional methods is so small that their number would be unfeasible for a global intervention, moreover when many of those have extremely conservative approaches towards increasing “comfort standards” and reducing energy consumptions.

As mediators between interior and exterior, buildings control flows of energy and matter including, excluding or moderating the often conflicting needs of those who, with their real or virtual presence, give the existing shell a meaning (Brito and Gameiro da Silva, 2012), and energy needs (Janda, 2011). This close relation between buildings and their

inhabitants, with their varied/variable habits and wide social contexts is not a problem, but the solution. But how can they be included in our legislative framework?

### ***Energy codes strategies and their impact on rehabilitation and innovation***

The Energy Security and Climate Change issues are one of the century paradigms that must inevitably deal with buildings, as the sector is responsible for 30% of the global annual GHG emissions and for 40% of global energy consumption (UNEP, 2009). In Europe, where the existing building stock ranges from those maintained and optimized throughout the centuries to brand new zero energy buildings that emerge as statements of a heliotechnical mechanicism (Fernández-Galiano, 2000) the sector has challenges. In the European building stock new buildings represent only about 1-2% of the total building area, a number that is expected to plunge due to demographical and financial constraints.

News identify older building areas as more energy efficient than recent ones in New York (Navarro, 2012), while studies demonstrate that the investment on existing buildings upgrade has lower environmental impacts (PGL, 2011) and a greater potential in reducing energy consumption in the medium term (Brito and Gameiro da Silva, 2012). Meanwhile an ongoing monitoring of an existing 14-16<sup>th</sup> century building (Brito, 2016b) depicts thermal interior/exterior variance temperatures around 10°C without acclimatization or user intervention, a long known and reported feature (Fathy, 1986) were natural ventilation, the walls inertia the humidity management of the gypsum wall materials play an important role, guaranteeing that the majority of the days “adaptive comfort” levels (Guedes et al., 2009; Nicol et al., 2012) are accomplished without energy consumption, stating the potential of the existing passive technology and the importance of outcome-based regulations to harness and extend this potential.

Energy codes relevance in achieving (measurable) results is demonstrated (Cochrane and Dunn, 2010; NBI, 2017), and so are associated risks: “as we make energy codes more and more stringent and more and more widely applicable, these frameworks present many obstacles to achieving deep energy savings in existing buildings” (Denniston et al., 2010). In fact most of the energy codes are linked to one or more legal strategies, each with specific advantages and disadvantages that have difficulties when embracing scale:

- **Prescriptive strategies** define a set of calculation and constructive solutions that comply with given framework, often addressing a virtual "model" that represents the minimum level of energy performance. A simplified model of the intended reality and the virtual model are adapted to the expected location and then performances compared, resulting an energy rating. The main advantage stems from the ease of compliance and verification in the situations for which the regulation was designed, whereas the main disadvantage derives from difficult integration of diversity like existing buildings or innovative solutions: in these cases, variations are brought into conformity with regulations, or ignored if not recognized by managing entities, raising obstacles to knowledge creation and transference to industry;
- **The modelling performance strategies** are usual in large service buildings, involving the simulation of two Building Energy Models (BEM): the design team proposal is compared to a calibrated model complying with minimum regulatory requirements, from which results the energy rating. The advantages result from the ability to integrate all the model-“able” solutions and technologies, and to provide a preliminary evaluation, allowing a shift from experience based knowledge to a paradigm of virtual experimentation and multi-criteria analysis. The disadvantages

result from modelling costs, progressively lower, the rare integration of the different project areas in three-dimensional databases (BIM), and the direct relation between model quality and the result: the simulation of existing buildings requires detailed representation of all mediation and control elements, making the "total simulation" unlikely in daily practice, and some results significantly different from reality;

- **"In situ" performance evaluation strategies or "Outcome-based"** (Cochrane and Dunn, 2010) regulations confront designers with a threshold number or percentage to be achieved, where project options and equipments are designed to meet or exceed these objectives (PlaNYC, 2013). The threshold number may be measured directly in place after works execution, while the evolution percentage threshold entails a preliminary assessment of the building under study, quite useful to identify the best intervention strategies (Brito, 2016b; Mørck et al., 2016). The advantages range from including the owner, designers and technicians around a common goal all the way to new optimization possibilities that arise from knowing the building behaviour and real consumption in its context. Main disadvantages include the need to develop and test methods and equipments to evaluate, "benchmark", the performance of the existing buildings quicker and at a lower cost –but even these are opportunities for applied investigation and innovation.

This simplification invites the reader to an overview of the legal strategies that better match their specific context, to perform a critic approach to the local validity of the referred advantages and disadvantages, but also to provide a glimpse on how neighbourhood scale approaches can dilute disadvantages and favour user involvement. But what happens in practice, in our buildings, in our neighbourhoods?

### ***Contrasting "rehabilitation" practices***

Urban rehabilitation is again in the media, alongside with claims of a better quality for the users and a new life for city centres. Unfortunately the terminology is used indiscriminately, and practice reveals three main intervention extremes that share the disrespect for centuries of empirically assimilated knowledge:

- **Historic conservative approaches** fail to provide safety and comfort to users, leading to progressive abandonment, turistification and urban sprawl, often contradicting the dynamics of history and buildings as most of the existing examples symbolize a versatility that made them useful throughout the times;
- **"make-up" interventions** cover building pathologies with layers of gypsum board or anti-fungi paints, on the expense of the building user's health and safety, or
- **"regeneration interventions"** that stuff a new building inside the shell of an existing one, on the expenses of the owners and adjacent buildings, now subjected to "pounding" effects on the occurrence of seismic events (Egbelakin et al., 2013).

In "make-up" interventions the incapacity to acknowledge the original behaviour of buildings and the cause of the eventual existing pathologies induces decision makers to "improve" the buildings look and the boundary thermal resistance using gypsum board, insulation materials and efficient windows, unaware that the loss of the original inertia is bound to reduce the buildings' passive behaviour and, in many cases, impose on the existing walls extreme conditions that lead to mould and potential health hazards to the users. In the residential sector the problem worsens as many of these works are reported as "conservation or maintenance", exploiting the lack of verification by public officials to introduce changes that may result in serious building vulnerability.



The “regeneration interventions” derive frequently from the incapacity to understand the physics, construction and maintenance processes of existing buildings, sometimes to the need to observe inadequate legislation and sometimes due to significant changes of use, although many of these are evident already when choosing the building. Although several studies identified the rehabilitation, renovation or retrofitting of existing buildings as financially more attractive than demolition and reconstruction (Balaras et al., 2005), and that it *“can take between 10 to 80 years for a new energy-efficient building to overcome, through more efficient operations, the climate change impacts that were created during the construction process”* (PGL, 2011) the belief that “new is better” forgets that the oldest buildings of the concrete or iron technology are just one hundred years old, while a large amount of existing masonry buildings are still standing for more than 500 years.

Moreover the diversity of existing buildings, the continuous change of teams and the lack of contextualization and evaluation efforts make these “building rehabilitations” an eternally new activity with a small learning curve, translated in high costs.

### ***Matching Energy Efficiency, Energy Security, Resilience, Sustainability and people?***

Energy Efficiency (EE) includes, but is not limited to, the efficient use of fossil or renewable energy. In *“Factor Four: Doubling Wealth, Halving Resource Use”* (Weizsacker et al., 1998) demonstrates that reducing needs through energy conservation measures (reduction of thermal losses or excess solar gains, among others) affects systems size and consumption, with direct impact on renewable energy costs, produced locally or imported from favourable spots. But other contexts impose.

Energy Security issues may conflict with EE, as the European Union imports “53% of the energy it consumes. Dependence (...) refers to crude oil (almost 90%), natural gas (66%) and, to a lesser extent, solid fuels (42%) and nuclear fuels (40%)” (EC, 2014), which inevitably influences European policy and strategy (EC, 2015).

Resilience, *“The capacity to recover quickly from difficulties; toughness.”* (OD, 2017) is another issue we tend to forget. In 2009 over 350,000 Portuguese clients were affected by an electric network failure between December 23 and 28 (EDP, 2010), leaving many of them also without water. In the recent forest fires power outages resulted in water and communications outages (DN and Lusa, 2017)

Sustainability requires a holistic vision (macroscale) of the potential of each neighbourhood (mesoscale) and each building (microscale) to reduce impacts and favour local and global co-benefits. Neighbourhoods appear as the appropriate scale and setting to match all of these together and to match collective expectations.

### ***Past, present and future stakeholders***

Stakeholders in building construction, use and rehabilitation process include those who propose and implement policies, property developers, construction managers, owners, occupants or simple visitors, to name a few. Each of them is responsible for decisions that will impact the building emissions level over its lifetime, but the lack of coordination between them results in an overwhelming quantity of lost small reduction opportunities (UNEP, 2009, p. 2009): *“the variety of buildings, climate locations the multitude of stakeholders and interests, (...) [and the] lack of clear and verifiable indicators with which to measure and compare energy consumption makes it difficult to gauge the savings derived from energy efficiency improvements. (...) [This] lack of awareness about low cost energy efficiency measures [and the option for not accounting] the life-time running costs of the*

*building because these are not paid for by the property developer*" (idem), postponing opportunities for change in attitudes and behaviours, and corresponding energy consumption reductions (Dahlbom et al., 2009).

Energy consumers' behaviour is reported (Brohmann et al., 2009) as a contextual interdependence that includes the diverse roles of the user as market participant, employee, citizen and family member, overlapping economical, psychological and sociological vectors that are frequently dismissed in the energy efficiency focused approaches. These influential context factors define barriers that range from lack of integrated knowledge by owners, installers, advisers, consumers on the legal, technical, operational and financial aspects of the problem to lack of experience in long decision-making processes. The analysis of the problem and strategies available should not forget that improving the energy performance of buildings is not a factor that drives the users or owners to act (Ideal EPBD, 2012); and that the human factor has a significant impact on spreading the desire for change. In fact the promotion of the "building users" towards a participant role as "building consumers" and buildings from "objects" to "services" would configure a leap towards healthier and safer building use (Brito and Gameiro da Silva, 2012).

What actions are possible in a context of uncertainty where climate changes are expected to impact our environment, economy and society (UNEP, 2009, p. 2009), and even the way we deal with problems?

### **Methods and arguments: we do better together**

The intervention on buildings is an opportunity to reorganize the existent energy and matter and, as such, a statement that must recognize the validity and context of the previous interventions and relations that kept those areas as distinguishable entities. The inadequate response to these needs and expectations evicted people and functions away from the city centres, the most privileged locations, favouring urban sprawl (Jacobs, 1961) and infrastructure/pendulum-associated increased consumptions. Can sustainable rehabilitations match contemporary needs and expectations?

A recent investigation on the upgrade process of an UNESCO setting historic building to "nearly Zero Energy Building" Zero goals (Annex 56 team et al., 2017; Brito, 2015) demonstrated that by matching deep assessments of traditional knowledge (Brito et al., 2014c) with "Cost-effective energy and carbon emission optimization in building renovation" (IEA EBC A56 team, 2017) calculations with the better renovation approaches and technologies (Brites et al., 2013) for each case, very good performance levels can be achieved (Mørck et al., 2016).

However the same research warns of persistent problems in individual interventions (Brito, 2016a), where most users/owners do not have financial resources to invest and reflect the cost of improvements in savings / income, nor the technical capacity for an informed choice, nor the scale to negotiate acceptable investment and maintenance costs.

Efficiency savings are often absorbed by the increased operation and maintenance costs of new equipments, leading current European efforts to provide end users with energy services like heat and light (Heiskanen et al., 2009) instead of energy sources (electricity or fossil fuels), a viable efficient and cost effective alternative. Optimal scale increases efficiency while lowering operational and maintenance costs.

### ***Neighbourhood as an opportunity***

*"Fagli mestiere a vivere con molti (Make it your business to live with many others)"*, said Fra Paolino in 1314, in a clear advice to enjoy your neighbours diversity as a channel towards a better engagement with the city and the world (Duby, 1993), to scale collective potential, to show results. The larger, yet contained, context of neighbourhoods renders deep assessments of characteristic buildings feasible, benchmarking and dynamic simulation costs acceptable and prescriptive approaches more informed, favouring enough detail for an adequate integration of the advantages of the referred "Energy codes strategies" (page 3), a common discussion ground and an evolving learning curve for "rehabilitation" practices (page 4) and the measurable results (page 5) that a controlled system can provide. Matching several approaches can optimize the learning curve, making the case for a record on successes, failures and evolution (see Conclusion), but other advantages prevail.

### ***An extended market for Energy Service Companies***

Harnessing the *"many small reduction opportunities scattered across millions of buildings"* (UNEP, 2009, p. 2009) is difficult in B2C (business to consumer) activities when compared to B2B (business to business): negotiating a service with a reduced number of stakeholders is always easier and faster, resulting in lower costs.

Proven effective examples are the Energy Service Companies (ESCOs) that propose B2B models with mutual gains and effective consumption reductions: instead of supplying energy (electricity, others ...), ESCOs provide the service that the customer wants (water hot, lighting, ...) freeing the industry from operation and maintenance costs, paying their investment while guaranteeing significant savings with efficiency and renewable solutions: lower costs for the industry and for the environment. With such advantageous solutions available, why doesn't industry take the initiative? Industry does not have the time, financial availability, core knowledge and negotiating capacity to make right choices and adequate maintenance of the equipment; and here they resemble neighbourhoods and building users.

In the exploratory paper "Residential buildings as expanded territory for ESCOs" (Brito et al., 2015), neighbourhoods are proposed as B2B stakeholders, allowing ESCOs, whose market is close to saturation, to expand their territory. The extrapolation of Montarroio's results to the street, neighbourhood and city, and the proposed aggregation of renewable energies in public buildings to scale up and facilitate installation and maintenance, reducing present and future costs, earned constructive criticism from researchers, politicians, makers and industry present at the European Council for an Energy Efficient Economy.

"Common Efficacy" improved this neighbourhood approach to a convincing point, earning in Paris the "2015 VINCI Innovation Awards" in the category "Urban Services & the Connected City" (VINCI et al., 2015) (video@ <http://www.uc.pt/en/efs/destaques/2016/vinci>)

### ***Harnessing more value for less money***

A more self-centred neighbourhood approach was proposed for the United States in the ACEEE Summer Study 2016 panel "Net Zero, Net Positive" with the title "From the 16th to the 21st century: upgrading Traditional Knowledge to approach Net Zero goals in existing neighbourhood upgrades (ZERH-NU)" (Brito et al., 2016), led by one of the great researchers of this topic (Torcellini et al., 2006). "Common Efficacy" (VINCI et al., 2015) was matched with individualistic collective actions like the construction of a garden by its inhabitants in Pacifica and the commercial scale neighbourhood methodology of the "Solar City" company. The argument that residents of consolidated neighbourhoods can maintain or increase the

value of their home/neighbourhood, and benefit others beyond it, was outlined in a presentation that received a written compliment from the Energy Efficiency California staff (Meyer and Brito, 2016) for its potential to lever disadvantaged communities.

### ***Safeguarding people's well-being and investments with Energy Efficiency***

The interest of a multinational ESCO such as VINCI lead to an invitation by the Joint Research Centre in Ispra, Italy to contribute to "A roadmap for the improvement of seismic and eco- efficiency of existing buildings and cities" (Brito, 2016c). European entities dealing with earthquake risk mitigation see in neighbourhoods the opportunity to protect people, goods and investments in Energy Efficiency, and in ESCO models the financial, technical and contractual capacity to make the necessary changes.

Matching other needs beyond Energy Efficiency is key to attract users' interest, as the growth of "do it yourself" (DIY) stores and the space dedicated to bathroom and kitchen improvements denounce that investment capabilities on "house tuning" are significant, which matches responses from interviewed building owners (IDEAL-EPBD, 2011).

### **Results and discussion**

The buildings we still recognize assimilated water networks and wastewater disposal, electricity and artificial lighting, new people and new uses. Before adding "solutions" an effort should be made on studying the previous (and prevailing) infrastructures and understanding, through their evolution, possible futures for the currently intended upgrade.

Technology-driven products and solutions often fail massive implementation due to crossed, interdisciplinary causes like the inability to answer to the user's needs and expectations, incapacity to differentiate from existing solutions, difficulty to integrate innovative solutions in organizational practices and incompatibility in specific environments: *"one credo of modern living is reductionism, the breaking down of a problem in simpler units and the belief that if we can study and understand directly this simple units, we can reassemble the whole structure in a logical fashion"* (Williamson et al., 2002).

An evolution towards the upgrade of existing buildings and neighbourhoods must privilege results: are the IEQ parameters guaranteed in the majority of the year without excessive energy consumption? Are the building users healthy, happy and safe while using the building? Are the investors recognizing added-value from their investments? Is the upgrade process evolving in knowledge, stakeholders' participation, applied innovation and effective total energy consumption reductions? Is change attractive?

Neighbourhood interventions have the scale for hybrid codes that go beyond energy, referred above, the right size for middle-out approaches (Janda and Parag, 2013) but also the proximity to care for the Sustainable Development Goal (United Nations, 2016) of leaving no one behind, with advantages for all.

Collective goals like Climate Change mitigation and Sustainable Development cannot be solved individually. The option for a voluntary engagement to achieve pre-negotiated targets for each neighbourhood would provide "win-win" results to all engaged stakeholders (Table 1), but also provide for quantitative and qualitative indicators that would favour analyzes and conclusions extrapolation, enriching other neighbourhoods.

Table 1: Advantages for all (neighbourhood) scale stakeholders

Users	Involvement on the decisions that affect them, allowing them to choose the solutions best fit their preferences, needs and expectations; better negotiation scale and status; complementarities and co-authorship, favouring social cohesion and interaction; fail-safe strategies and possibility to evolve (upgrade) their solutions; confidence to test solutions proposed by industry; close connection to the technical and investigation teams; results visualization would foster better confidence to face uncertainty and to embrace new goals;
Owners	Opportunity to understand directions, observe and accompany interventions and plan ahead; better negotiation scale and status; advice from technical teams;
Technical teams	opportunity to engage investigators and highly trained personnel in a progressively growing market, to enhance team-work capabilities and engage with other companies in horizontal solutions and services and create long-lasting relations with the other stakeholders;
Investigators	access to real life investigation scenarios, direct contact with users, companies and entities, favouring investigation support and financing, thrilling teams and facilitated future transference to market or industry
Universities	a real context for applied innovation, a coherent environment for product-to-market development, financial endorsement of investigation lines, direct contact with potential private sources of investment and, by introducing their students into real-life scenarios, challenging curricula, more and better investigators, increased employment opportunities and, in the end, more attractiveness to the upcoming students;
Energy service companies	access to real data essential to make scale decisions like the viability of neighbourhood heating systems or heat storage, direct contact with municipal and industry decision-makers and scientific support of their proposals;
Cities:	opportunity to participate in leading investigation towards energy consumption reduction, fulfilling their "Covenant of Mayors" commitments, to create attractive environments for engaged users, companies, investigators and institutions settlement, to promote the attractiveness of their existing building stock, create local jobs and to build consistency and partnerships to substantiate candidacies for improvement funds
Services and industry	access to state of the art investigation, resource sharing, the possibility of reformulating products towards evolving needs or to develop new products or approaches to meet the specifications, personnel-training opportunities to prepare widespread interventions, demonstration sites and external visibility;
Utilities	access to real data, stakeholders and users to evaluate new market-insertion strategies for technologies like smart grids or demand-side response in a fruitful open environment;

A neighbourhood scale upgrade strategy can link the virtues of having defined objectives and varied methods of achieving them with the possibility to phase investments and verify progressive gains (Menassa, 2011), reducing uncertainty related barriers. In this perspective the upgrade potential of a neighbourhood is directly connected to its initial and evaluation phases, and to the ability to sustain change.

In the initial phase a prognosis meeting is necessary to identify present and future needs, evolution and physical space for uncertainty, while the successive evaluation phases

are strongly dependent from the ability to measure and interpret each intermediate result, and the ability to introduce new solutions or concepts. Measurable goals must be framed collectively within the stakeholders' range of knowledge and feasibility in open discussion groups, fine-tuned to evaluate unwritten messages and eventual distortions, and benchmarked in use to evaluate their future extension to other neighbourhoods.

"Watt" is only one question. "How" do we start? In Conclusion our own incapacity becomes a baseline to learn from others, and to invite our neighbourhood to join together.



## Conclusion

We are all energy deficient, a chronic reality that grows acute with each passing day. It is important to assume this deficiency "*1 Not having enough of a specified quality or ingredient. 1.1 Insufficient or inadequate. (...)*" (OD, 2017) to get along with it. In a century marked by Climate Change mitigation and hopes for Sustainability, we fail to do our part.

Let's look at our homes to recognize this deficiency. Most of us lack the economic freedom to invest and deduct this cost in savings, lack technical capacity for informed choice or to apply for subsidies, and lack scale to negotiate acceptable investment, operating and maintenance costs. What will you do when the next equipment fails? Keep the same system in the next 15 years, or swap? Which one? This decision, occurring daily in thousands of homes, should not be solved by the passing technician. Even those who live in Net Zero houses should not rest, for as long as they are few, their effect will be null: we fail anyway.

With many taxes and fees, legislative changes and publicity make an effort on our behalf, but results are lacking and underlying directions and senses still not visible: just look at your home, and to those around you. Without references we are blind: we are taken where they want us, every day, not where we have to go. Legislation persists on not calling the inhabitants of buildings, those responsible for the selection of (governments) buildings, efficient appliances and their correct use in the processes that affect them. In our name, and for our good, someone decides for us without consulting us.

To assume this small deficiency is an opportunity for us to surpass and complement ourselves, to learn and recognize the merit of others who have organized themselves to assert their rights. The United Nations International Day of Disabled Persons (December 3), 2004 motto, "Nothing about us without us" should inspire us. Knowing that the collective goal of sustainability cannot be achieved with individualistic, voluntary or imposed strategies, assuming this energy deficiency can facilitate greater collective participation. It is important to assume our "imperfection" in the design, use and maintenance of buildings and equipment, our "lack" of capacity to describe what is intended of us, our houses, our cases, and the "gaps" that incapacitate us to question the suitability of interests specific to our needs and to the national design, whatever it may be. Living with disability implies a constant effort of self-overcoming, searching for the alternatives that best complement us, those better in line with our way of life and of the others around us.

Stop here to look at your house, and look around. How much would we save by knowing the experience of our neighbours, or by doing a "group purchase" of equipment or maintenance exemplified previously? Can we make sure no one is left behind? The examples stated in the Methods chapter are just a few demonstrating that the neighbourhood is a stable and secure innovative environment for all stakeholders.

### ***On the potential of a Neighbourhood Energy Accessibility Plan (NEAP)***

Acknowledging the effect of our decisions on our well-being and that of others around us, near or far, is essential for a mutual co-responsibility that favours safety of investment and people, and a clear alignment with sustainability practices (Brito, 2017).

A Neighbourhood Energy Accessibility Plan (NEAP) can tell what is expected of us, how we can participate, where we would like to go and those with proven references in our area, among other information. And also document our successes, failures and strategies, so that others, energy deficient like us, can progressively contribute to the most attractive and effective solution for each neighbourhood.

## Acknowledgements

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## References

- Annex 56 team, Höfler, K., Maydl, J., Venus, D., Sedlák, J., Struhala, K., Almeida, M.G. de, Ferreira, M.A.P.S., Brito, N.S., Baptista, N., Fragoso, R., 2017. Shining examples of cost-effective energy and carbon emissions optimization in building renovation\_2nd Edition (Annex 56). Universidade do Minho.
- Brites, G., Brito, N.S., Costa, J., Gaspar, A., da Silva, M.G., 2013. Solar Cooling as an Optimization of Conventional Solar Thermal Systems for Existing Buildings' Upgrade Interventions, in: *Clima 2013 - 11th REHVA World Congress, 8th International Conference on Indoor Air Quality, Ventilation and Energy Conservation in Buildings*. Prague.
- Brito, N.S., 2016a. Mismatch, exclusion and inclusion: threats / opportunities for Historic Buildings in the current Energy Efficiency paradigm, in: *Energy Efficiency and Comfort of Historic Buildings*. Presented at the Energy Efficiency and Comfort of Historic Buildings, Belgian Building Research Institute (BBRI, Flanders Heritage Agency, Brussels.
- Brito, N.S., 2016b. IEA EBC Annex 56 Detailed Case Study "Montarroio," in: IEA EBC Annex 56 on "Cost-Effective Energy and Carbon Emissions Optimization in Building Renovation." University of Minho, Guimarães, Portugal.
- Brito, N.S., 2016c. Common Efficacy: from what we "have and know" to what we "need and expect," in: Caverzan, A., Lamperti Tornaghi, M., Negro, P. (Eds.), *Proceedings of SAFESUST Workshop: A Roadmap for the Improvement of Earthquake Resistance and Eco-Efficiency of Existing Buildings and Cities*. JRC Science Hub.
- Brito, N.S., 2015. draft "Montarroio Shinning Example" for IEA EBC Annex56: enhanced version. All comments and questions are welcomed, and will surely enhance the quality of the final publication. <https://doi.org/10.13140/RG.2.1.1029.9600>
- Brito, N.S., Brites, G., Castela, R., Fonseca, P., Gameiro da Silva, M.C., 2014c. Learning from Traditional Knowledge towards engaged inhabiting, in: *Heritage and Landscape as Human Values*. ICOMOS (International Council on Monuments and Sites) 18th General Assembly and Scientific Symposium. Presented at the Heritage and Landscape as Human Values, ESI, Florence, Italy, pp. 389–396. <https://doi.org/http://dx.doi.org/10.13140/2.1.2561.9202>
- Brito, N.S., Gameiro da Silva, M.C., 2012. Upgrade Opportunities for Buildings in City Centres. *The European Physical Journal Conferences* 33, 05008. <https://doi.org/http://dx.doi.org/10.1051/epjconf/20123305008>
- Brito, N.S., Janda, K.B., Castela, R.O., Gameiro da Silva, M., 2016. From the 16th to the 21st century: upgrading Traditional Knowledge to approach Net Zero goals in existing neighborhood upgrades (ZERH-NU). Presented at the 2016 ACEEE Summer Study on Energy Efficiency in Buildings: From components to systems, From Buildings to Communities, ACEEE, Pacific Grove, California.
- Brohmann, B., Cames, M., Gores, S., de Best-Waldhober, M., 2009. IDEAL-EPBD\_Conceptual framework on user behavior - With a focus on energy savings in buildings -.
- Cochrane, R., Dunn, L., 2010. *Energy Codes 101: A Primer for Sustainability Policy Makers*. Preservation Green Lab, National Trust for Historic Preservation, Seattle.
- Dahlbom, B., Greer, H., Egmond, C., Jonkers, R., 2009. *Changing Energy Behavior. Guidelines for Behavioural Change Programmes*. Instituto para la Diversificación y Ahorro de la Energía.
- Duby, G. (Ed.), 1993. *A History of Private Life: Revelations of the Medieval World v. 2*, New edition edition. ed. Harvard University Press, Cambridge (Mass.); London.
- EC, (European Commision), 2015. *Energy Union and Climate [WWW Document]*. URL [http://ec.europa.eu/priorities/energy-union-and-climate\\_en](http://ec.europa.eu/priorities/energy-union-and-climate_en) (accessed 1.2.16).
- EC, (European Commision), 2014. *European Energy Security Strategy*. Brussels, SWD(2014) 330 final.
- Egbelakin, T., Wilkinson, S., Potangaroa, R., Ingham, J., 2013. Improving regulatory frameworks for earthquake risk mitigation. *Building Research & Information* 41, 677–689. <https://doi.org/10.1080/09613218.2013.819546>

- EU, (European Union), 2010. 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast).
- Fathy, H., 1986. *Natural Energy and Vernacular Architecture: Principles and Examples with Reference to Hot Arid Climates*. University Of Chicago Press.
- Fernández-Galiano, L., 2000. *Fire and Memory: On Architecture and Energy*, 1st ed. The MIT Press.
- Guedes, M.C., Matias, L., Santos, C.P., 2009. Thermal comfort criteria and building design: Field work in Portugal. *Renewable Energy* 34, 2357–2361. <https://doi.org/10.1016/j.renene.2009.03.004>
- Heiskanen, E., Johnson, M., Saastamoinen, M., Vadovics, E., 2009. Creating Lasting Change in Energy Use Patterns through Improved User Interaction, in: *Conference Proceedings. Presented at the Joint Actions for Climate Change Confererce, Aalborg*, pp. 134–135.
- Historic England, 2017. Listed Buildings | Historic England [WWW Document]. URL <https://historicengland.org.uk/listing/what-is-designation/listed-buildings/> (accessed 11.13.17).
- Ideal EPBD, 2012. Ideal EPBD: European project on consumer response to energy labels in buildings [WWW Document]. URL <http://www.ideal-epbd.eu/> (accessed 5.22.12).
- IEA EBC A56 team, 2017. International Energy Agency (IEA) Energy in Buildings and Communities (EBC) Annex 56 on “Cost Effective Energy and Carbon Emissions Optimization in Building Renovation” [WWW Document]. URL <http://www.iea-annex56.org/> (accessed 11.5.17).
- Jacobs, J., 1961. *The death and life of great American cities*. Random House.
- Janda, K.B., 2011. Buildings don’t use energy: people do. *Architectural Science Review* 54, 15–22. <https://doi.org/10.3763/asre.2009.0050>
- Janda, K.B., Parag, Y., 2013. A middle-out approach for improving energy performance in buildings. *Building Research & Information* 41, 39–50. <https://doi.org/10.1080/09613218.2013.743396>
- Menassa, C.C., 2011. Evaluating sustainable retrofits in existing buildings under uncertainty. *Energy and Buildings* 43, 3576–3583. <https://doi.org/10.1016/j.enbuild.2011.09.030>
- Mørck, O., Almeida, M., Ferreira, M., Brito, N.S., Thomsen, K.E., Østergaard, I., 2016. Shining examples analysed within the EBC Annex 56 project. *Energy and Buildings* 127, 991–998. <https://doi.org/10.1016/j.enbuild.2016.05.091>
- Navarro, M., 2012. New York City’s Effort to Track Energy Efficiency Yields Some Surprises. *The New York Times*.
- NBI, (New Buildings Institute), 2017. *Implementing an Outcome-Based Compliance Path in Energy Codes: Guidance for Cities*.
- Nicol, F., Humphreys, M., Roaf, S., 2012. *Adaptive Thermal Comfort: Principles and Practice*. Routledge.
- NRH, 2017. National Register of Historic Places Official Website [WWW Document]. URL <https://www.nps.gov/nr/> (accessed 11.13.17).
- OD, (Oxford Dictionaries), 2017. discrimination | Definition of discrimination in English by Oxford Dictionaries [WWW Document]. Oxford Dictionaries | English. URL <https://en.oxforddictionaries.com/definition/discrimination> (accessed 11.13.17).
- PGL, P.G.L., National Trust for Historic Preservation, 2011. *The Greenest Building: Quantifying the Environmental Value of Building Reuse*. Seattle.
- PlaNYC, 2013. PlaNYC Green Buildings & Energy Efficiency [WWW Document]. URL <http://www.nyc.gov/html/gbee/html/home/home.shtml> (accessed 10.15.13).
- UNEP, U.N.E.P., 2009. *Buildings and Climate Change: Summary for Decision-Makers*. UNEP Sustainable Buildings and Climate Initiative, Paris.
- United Nations, 2016. *Sustainable Development Goals: 17 Goals to Transform Our World* [WWW Document]. United Nations Sustainable Development. URL <http://www.un.org/sustainabledevelopment/> (accessed 11.21.17).
- Weizsacker, E. von, Lovins, A.B., Lovins, L.H., 1998. *Factor Four: Doubling Wealth, Halving Resource Use - The New Report to the Club of Rome*, New Ed edition. ed. Routledge.
- Williamson, T.J., Bennets, H., Radford, A., 2002. *Understanding Sustainable Architecture*. Taylor & Francis, London & New York, N.Y.

## *Chapter 4:*

### *Sustainable urban design*

# **The Effect Of The Relationship Between The Height Of Building (H) And Width Of The Street (W) In Distribution The Physical Loads - Thermal And Visual – In The Street, For Saharian Cities, Case Study Of The City Of Biskra, Algeria.**

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## **Abstract**

The urban tissue depends on the logical relationship between built and non-built space in the distribution style of the physical loads in the free space - the street-. Where the ratio between height / width is the considered as a main controller in the amount of thermal and light energy that reaches to the street. The methodology of this research was due to the field of experience in order to raise the real values of the physical loads every two hours, each three consecutive days. Where adopted to the comparison of two main axes of the physical loads, they are 1-the thermal load, 2-the visual load, through the measurement stations that are positioned via the three types of the relationship between H/W, ( $h \geq 2w$ ,  $h=w$ ,  $h \leq 0.5w$ ). Where the street engineerings, ( open street, dihedral street, canyon street). Through the obtained results, we noticed and recorded the difference between these values in the three types of street engineering. The difference in the thermal values of the air reached  $4^{\circ}C$ , and the difference in the direct natural lighting periods of the high amount reached six hours. The conclusion, we can note the values difference between the three types of the relationship H/W. Where the street was of the high ratio between H/W ( $h \geq 2l$ ), which knows canyon street, is the less physical loads. Thus turns out the effect of the relationship between H/W to protecting the free space –street-. This is very important for desert cities.

**Keywords:** physical loads; street; the city of biskra; urban tissue; the height of built.

## **Introduction**

The typical study of the distribution of natural physical loads, is very important to guarantee the physical comfort of human within free space urban-street-, especially in the cities of desert, it is also obligatory principle for the survival of the cities of the desert (Boukhabla, 2013) where the physical comfort of these cities, is re-value and the fundamental authenticity of these cities (Jean, 2001). Where the role of urban tissue for protection of the free space –street- of the physical environmental loads.

## **The objectives**

- Studying the relationship of the effect of the H / W. To improve physical loads in urban space - street-.
- Identifying the best of the typical relationship between H / W, to improve physical loads in space -street- through comparative study between them.

## **Methodology**

The comparative method is the scientific methodology applied for this research. Where the theoretical axis, and the practical axis (identifies the urban environment, determines the tool to search the field work), at the last is the comparative and the discussion of the results (Qaoud , 2017).

- **The theoretical part**

### **The Physical Loads**

The street always receives light and thermal energy, which is the source of the sun, that the energy constitutes a load of the substances which component of the street (Cote , 2005). Where that energy is high form a burden for the human who uses the street so, the control of this energy is directly reflected in the urban physical comfort.

### **The physical ambience**

We can understand the concept of the physical ambience by the concept of the physical comfort, where it consists of thermal, visual, acoustic and olfactory comfort (Qaoud , 2017).

### **Thermal comfort**

The concept of thermal comfort formed by combining the climatic factors that affect the heat exchange between climate and human (Allen, 2011), so the thermal comfort is zone a very short period within a period of thermal equilibrium. That area reflects interaction between the components and combinations of the climatic factors that affect the heat exchange -human with climate-, to reach the case of thermal equilibrium. These elements which comprise the human activity that is practised, the coefficient of thermal insulation of clothing, air temperature, air speed, relative humidity, and the average temperature of surfaces surrounding (Nikolopoulou, 2004).

### **Visual comfort**

The field of optical radiation for visual comfortable and visual perception in a range between 100 to 1000 lux (Nikolopoulou, 2004). Where this area ensures levels of optical radiation for ease of performing the tasks and visual functions within the urban tissue (Loiseau et al, 1993), this area in which of shaded and sunny area, which is the cause of the human visual perception comfortable (Nikolopoulou, 2004).



## The relationship between H/W

### *The different Models of The street Engineering*

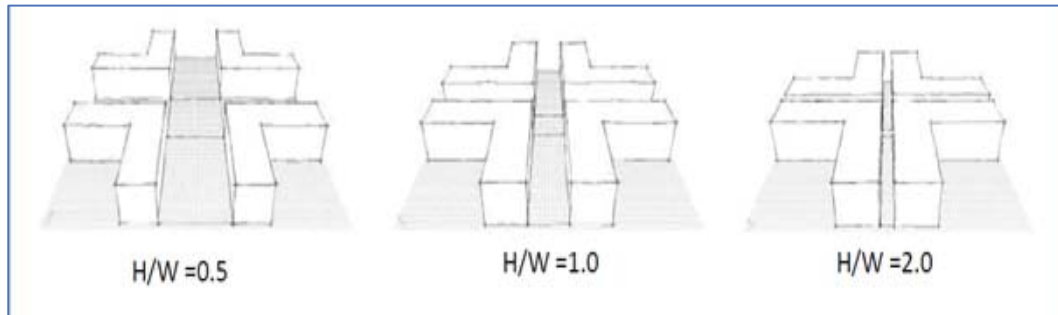


Figure 1. The different models of the street engineering. Source. Khaled, 2008.

The relationship between the height of the facade and the view of the street is represented by three geometric patterns ( $H \geq 2W$ ,  $H=W$ ,  $H \leq 0.5W$ )-( Open Street, dihedral street, Canyon street),( Khaled, 2008).

### **Density Construction**

The responsible of the height of the facade is density Construction (Allain,2006). This density which is controlled by two criteria. The first is the coefficient of the exploitation of land (CEI). The second is the coefficient of the occupation of the land (COI), (Panerai et al,2009).

Table 1. The different models of density Construction

Altitude	High or more (R + 6)	Medium (R + 2) to the (R + 5)	Low floor, ( R ) or (R1)
occupation of land			R upper floor
A strong 50-100%	Skyscrapers centrality	Residential building in urban residential building mass without elevator	Houses a central space
Medium 50-20%	High barriers	Little group buildings, accommodation a median (individual entrances)	Collectively houses or stripe cities housing
A weak up to 20%	Towers in green spaces	Low land	Individual paired, individual single, pavilion

- The practical part

### The site measuring stations

Distributing three stations on the tissues of the overall sample of the city as they are presented in the following figure. The street according to the direction: (North-west/south-east).

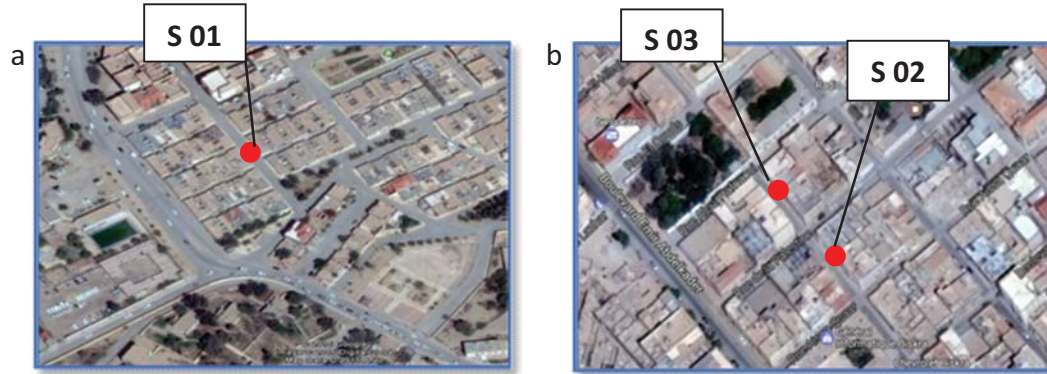


Figure 2. (a) The station (01). (b) the stations (03,02). source. google earth 2015.

### Description of measurement stations

**Station No. 01 . The low ratio between the height / width ( $H \leq W$ ). Open Street**

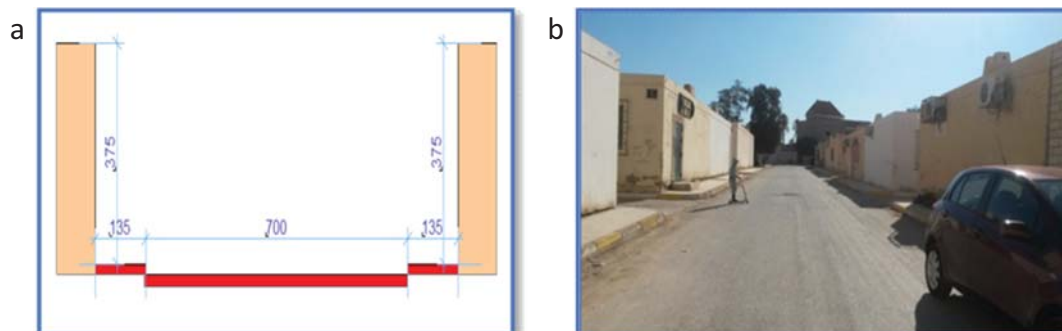


Figure 3. (a) Section of the station (01) . (b) view of the station (01). Source. Author.

**Station No. 02 . The average ratio between the height / width ( $H = W$ ). dihedral street**

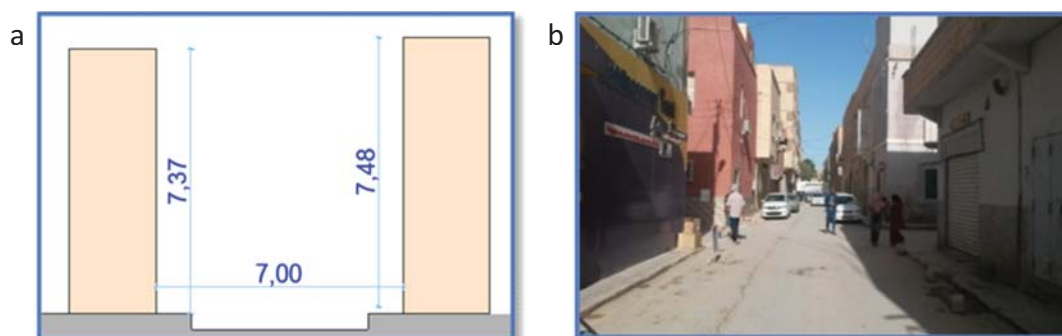


Figure 4. (a) Section of the station (02) . (b) view of the station (02). Source. Author.

**Station No. 03. The high ratio between the height / width ( $H \geq 2W$ ). canyon street**

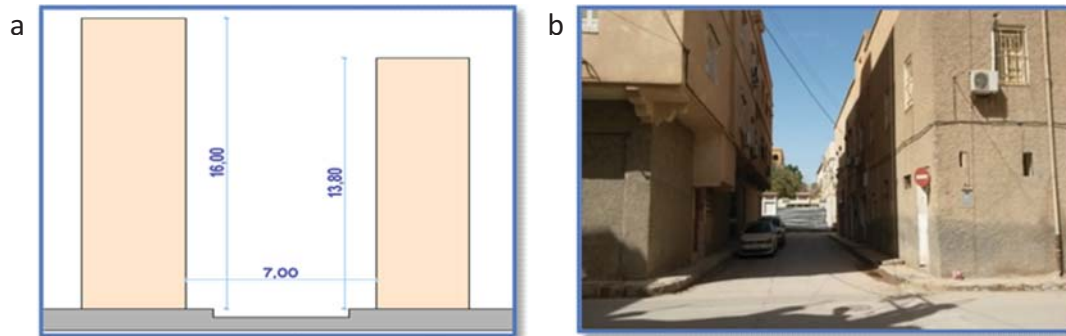


Figure 5. (a) Section of the station (03) . (b) view of the station (03). Source. Author.

**Measuring instruments used**



Figure 6. (a) Testo 480. (b) lux meter. source. Author.

**Results and discussion**

**Thermal energy- Air temperature for the three models of Streets, north west / south east**

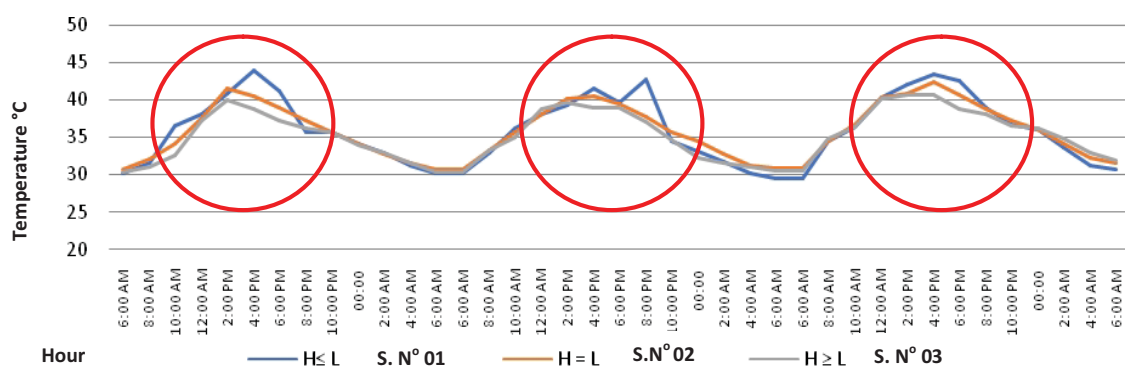


Figure 7. The level of air temperature. streets- North west / South east .Source. Author.

Through experience we record the station n°01: has higher values where they reached max a temperature of 44.4°, estimated total thermal energy  $6326 \text{ W/m}^2/\text{d}$ . Then the station n°02: where the values max a temperature of 42.3°, and estimated total thermal energy  $5314 \text{ W/m}^2/\text{d}$ . The station n°03 : where the values max a temperature of 40.6°, and estimated total thermal energy  $3288 \text{ W/m}^2/\text{d}$ . So we understand the temperature difference between the open street, canyon street, reached a 4°, and difference of estimated total thermal energy  $3038 \text{ W/m}^2$ . This difference in values is consequent of difference in the ratio between  $h/w$ , where the lowest values was in the canyon street. This result prove the impact of the constructivism density which responsible of the height of the building, where the relationship between height of building(H) and the section of street in reducing the quantity of thermal energy and improving air temperature.

### ***Thermal energy- temperature of the outer wall for modes of streets north west / south east***

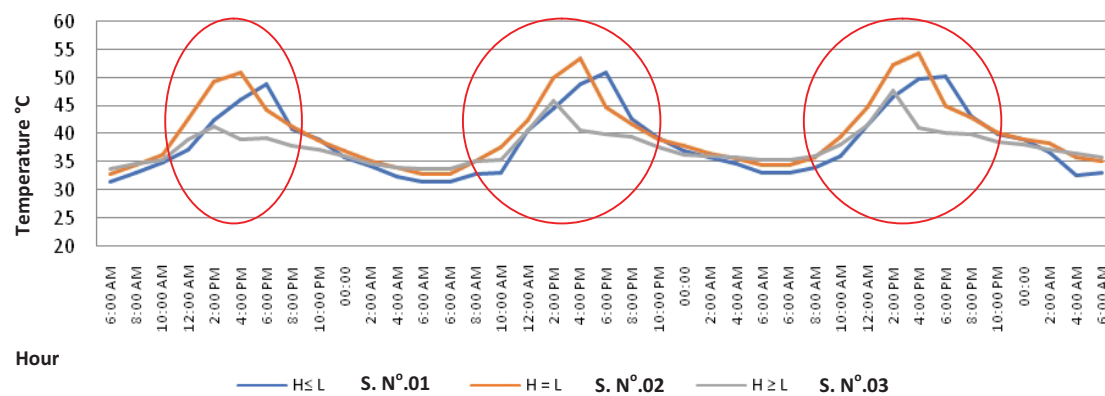


Figure 8. The level of temperature of the outer wall. streets- North west / South east .Source. Author.

Although different of the thermal coefficient of the wall material in the three stations, and according to measurement times. we record the period of the wall's acquisition of energy and the periods of loss, between the three stations. Where the station n°01: has higher time to acquisition of thermal energy which arrived to 12 hour in the day, where 14.5 hours of the day. And then the station n°02: where the time of acquisition of energy arrived to 10 hour in the day, where 14.5 hours of the day. And then the station n°03: where the time of acquisition of energy arrived to 08 hour in the day. So the time difference between the open street, canyon street, reached 4 hours. This means is the quantity of thermal energy of the open street s.n°01 is greater than that received by the substance of the canyon street s.n°03, which directly affects the temperature of the air and thus on the comfort of street user. This result prove the impact of the height of the building (H) and the relationship with the section of street (W) in reducing the quantity of thermal energy which reach to the outer wall.

### ***Thermal energy- temperature of The ground for modes of streets north west / south east***

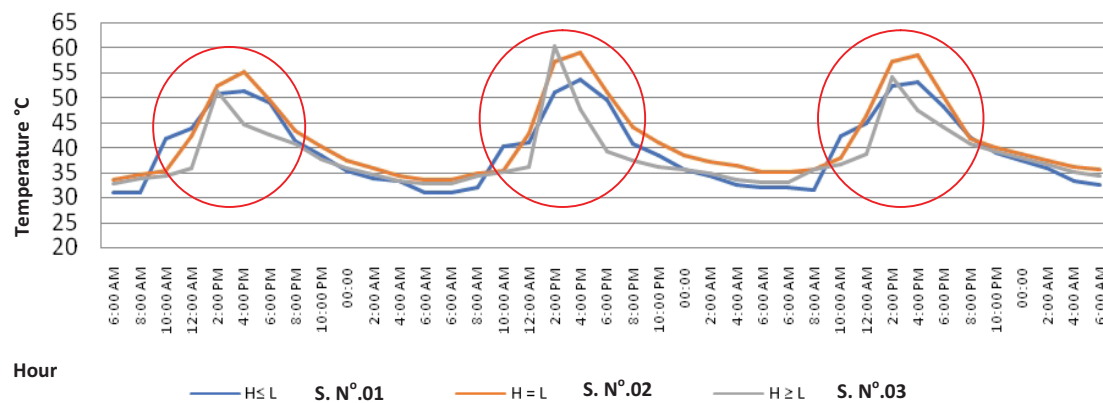


Figure 9. The level of temperature of The ground. streets- North west / South east .Source. Author.

According to measurement times. we record the period of the ground acquisition of thermal energy and the periods of loss, between the three stations, where the station n°01: and station n°02 acquisition of thermal energy which arrived to 10 hour in the day, where 14.5 hours of the day. And then the station n°03: where the time of acquisition of thermal energy arrived to 06 hour in the day. So the time difference between the open street, canyon street, reached a 4 hours. This is also means is the quantity of thermal energy of the open street s.n°01 is greater than that received by the substance of the canyon street s.n°03. This result prove the impact of the relationship between height of building (H) and section of street (W) in reducing the quantity of thermal energy that reach the ground.

### ***light energy- The level of natural lighting for modes of streets, north west / south east***

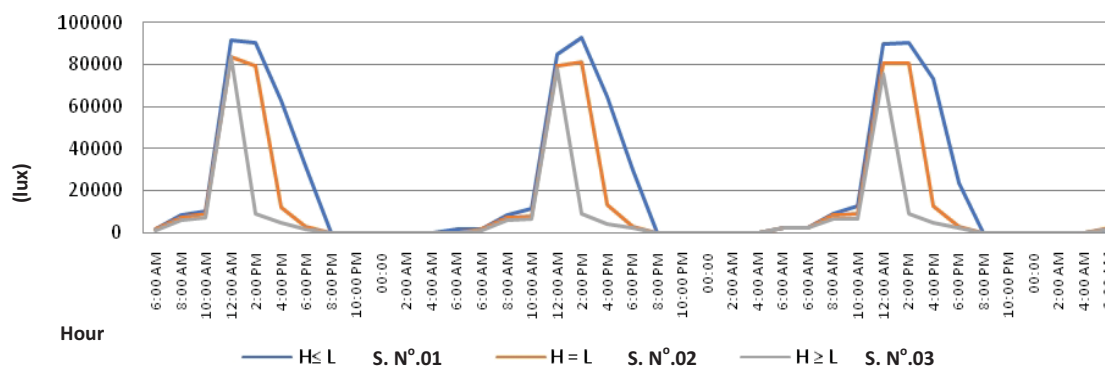


Figure 10. The level of natural lighting of streets. North West / South east. source. Author.

Through experience and according to measurement times where the station n°01: higher values reached max of level of natural lighting 90k/lux, and estimated total light energy in direct lighting 277.7 k/lux, this type of street is exposed to direct sunning 08 hours, where 14.5 hours of the day. Then the station n°02: the values max of level of natural lighting is 90k/lux, and estimated total lighting energy in direct lighting 176 k/lux, this type of street is exposed to direct sunning 06 hours of the day. The station n°03 : the values max of level of natural lighting 83.5k/lux, and estimated total light energy in direct lighting 83.5 k/lux,



where the street is exposed to direct sunning only two hours of the day. So the difference of estimated total lighting energy is 194.2k/lux between the open Street, canyon street.

This difference is consequent of difference in the ratio between H/W, where the canyon street – was Less time periods of direct sunning, and was less light energy. This result prove the impact of the constructivism density which responsible of the height of the building, where the relationship with the section of street (W), in improving of the level of natural lighting in the street.

## Conclusion

To conclude, the urban tissue is where we find more constructivism density and more proportion between h/w is the lowest in terms of physical loads applied in the street, because of the relationship between the height of the building (H) and section of street (W) is controller of the effectiveness of reducing the physical loads for the environment applied on the street and achieve the shade and alternation throughout the day. This is very important for desert cities in order to reduce physical and natural of loads, and improving the physical urban ambience for desert cities.

## References

- Allen, K . Translation. Ahmed, K (2011). The Standards Of The Design Warm Areas: Mketbh Anglo-Egyptian.
- Allain, R (2006). Morphologie Urbaine. Geographi Amenagement Et Architecture: Paris. Armand Colin.
- Boukhabla, M. Djamal, A (2013). The Effect Of Urban Morphology On Urban Heat Island In The City Of Biskra In Algeria: International Journal Of Ambient Energy, Vol 34:2.P 100–110.
- Cote, M(2005). La Ville Et Le Désert: Paris. Karthala.
- Jean, D. Edmond, B (2001). Les Milieux Désertiques. Paris. Armand Colin.
- Khaled, O (2008). Contribute To The Project In The Island Of Thermal Analysis Indicators: Memo Master. University Of Nantes.
- Loiseau, M, J. Terrasson, E. Trochel, Y (1993). Le Paysage Urbain: Paris. Editions Sang De La Terre.
- Nikolopoulou, M (2004). Concevoir Des Espaces Extérieurs en Environnement Urbain: Une Approche Bioclimatique. Centre For Renewable Energy Sources (C.R.E.S.) (<http://alpha.cres.gr/ruos/>) visit in 15/12/2015.
- Panerai, P. Jean, C. Jean-C, D (2009). Formes Urbaines De L'ilot A La Barre: Marseille. Editions Parenthèses.
- Qaoud, R. Djamal, A (2017). The Impact Of Constructivism Density Of The Urban Tissue In Improving The Physical Urban Ambience Of The Free Space - The Street- For Saharian Cities. The Study Of The Case City Of Biskra: Journal Energy procedia, Vol 119.P 201–2013.
- Qaoud, R. Djamal, A (2017). The Impact Of Constructivism Density Of The Urban Tissue In Improving The Urban Ambience- Thermal, Visual - Of The Street. For Saharian Cities. Casa Study Of The City Of Biskra: procedings plea 2017, Vol 01. P 820–826.



# Integrated Built Typologies: An Ecological Design Approach to Regenerate Suburban Quarries, Bangalore, India

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**Abstract:** Quarries are often synonymous with beautiful cities, spectacular monuments and infrastructure development since time immemorial. However, the environmental disarray that it may cause often remains invisible and undocumented. The narratives of quarries in the peri urban sectors of Bangalore city present a paradoxical picture to the environs, reimagined by its rulers over several centuries, as the garden city of India. Sites seldom remain silent; the photo essays and transect studies, introduced at the under-graduate architectural studio level, captured the conflicting characteristics of quarries. They reveal the socio-political and environmental mayhem woven by these abused landscapes. The studio methodology examines critical questions on the sustainable regeneration of these hidden landscape narratives and its integration with the built environment. The study is supported by rigorous qualitative and quantitative analysis; involving ethnographic studies to premise the socio-political concerns and subsequently a precise environmental mapping conducted to reveal the landscape vagaries. The design outcome illustrates the need for a paradigm shift in the conception of architectural typologies. It proposes an ecological approach of innovative built typologies to harness and integrate these abandoned urban voids as part of the built environment; thus, constructing the design impetus into the territory where the built meets the vagaries of abused landscapes. It illustrates a series of strategies and practices that may integrate the quarry with the built environment, in its efforts to regenerate life back to the landscape. Here, harnessing water and correcting the altered water network are hypothesised as fundamental to regeneration tactics. Hence, the design demonstrates, in detail a built structure which works both as a hydraulic structure and a building which houses a public function connecting the public squares with in the campus; the Centre for Environmental Education (CEE) India.

**Keywords:** Education, Studio, Regeneration, Environmental Design, Ecological Approach

## Introduction

“Abstraction and perfection transport us into the world of ideas, whereas matter, weathering and decay strengthen the experience of time, causality and reality”; writes Juhani Pallasmaa in *Hapticity and Time: Notes on Fragile Architecture*. Quarries, on a similar note, are often synonymous with beautiful cities, spectacular monuments and infrastructure development since time immemorial. However, the environmental disarray that it may cause and the narratives of abuse or decay of landscapes, often remains invisible and undocumented. The paper examines critical questions on the sustainable regeneration of these hidden landscape narratives. It proposes to generate inspirational spatial models to harness and integrate these urban voids as part of the city.

Sites seldom remain vacant; (Burns & Kahn, 2005) often, they offer different narratives. The paper engages the explorations in Architectural education on the narratives of a site in the process of making it into a place. The new uses and activities, create or even require new narratives. It therefore examines if the site matters in the design process. The engagement with the narratives of stone quarries (Figure 1) and the issues that they provoke, experiential, environmental, social and material concerns, in the peri-urban areas of Bangalore city in India add to the complexity of the exploration.

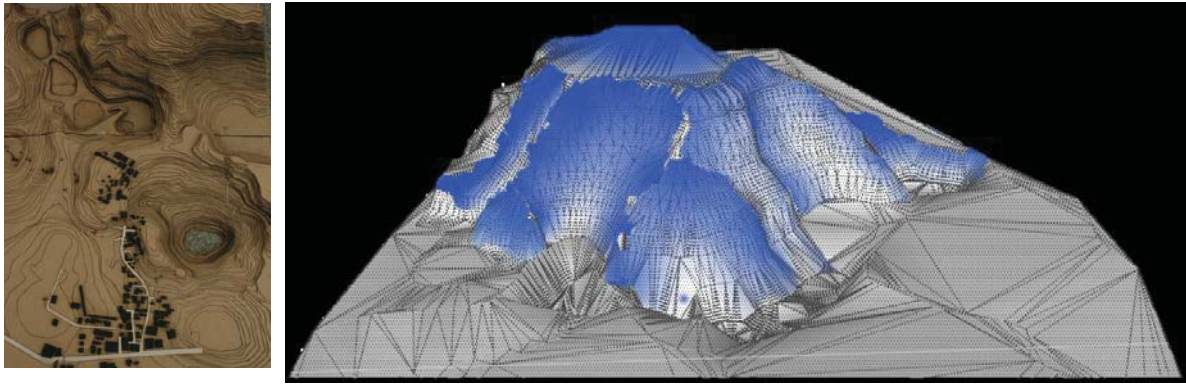


Figure 1. Model –Bettahalasur Quarry Bangalore

It follows a distinct design methodology intending to capture the contextual characteristics of landscape vagaries and social disarrays and to engage an awareness on how landscapes have been rescaled by political decisions. These transformations are induced by the mining activity during the past six to seven decades in the region. It proposes processes to evolve an integrated built typology, with the abused landscape, as a strategy towards sustainable development. The process entailed finding answers to how abused landscapes, the quarry-scapes, be meaningfully integrated with the city and how an ecological approach of design can integrate the scattered efforts in spatial design, social realm, landscape engineering, infrastructure planning, ecological restoration, sustainable agriculture and other disciplines. The paper therefore explores the process of sensitising environmental narratives in architectural education.

### ***Methodology of the Study and Design***

"We need to use a new collaborative integrated design process that can create new approaches and tools, and beautiful environments that can restore social, economic, and environmental vitality to our communities." writes Bob Berkebile, one of the world's most respected green architects. (Zimmerman, 2006) The integrated design process adopts a methodology embedded within two phases; the former phase engages an exploratory bottom-up method of documentation and subsequently a detailed environmental and social mapping of a selected area within the quarry. It intends to draw conclusions on the natural, behavioural and sensorial structure of the site. The latter phase, however, adopts case study method to evolve processes towards integrated design strategies. It intends to critique the design for its artful dialogue with the site narratives. The following two sections illustrate the process and outcome of these phases in detail.

### **Narratives of Quarries in Peri-urban Bangalore**

"Around the corner, in the distance, even out of sight, they conspire to illusion. When the surroundings change, the site and what has been built on it change too. Open may become closed; tall may become ordinary". (Burns & Kahn, 2005)

Stone quarries are found more or less everywhere, where there has been human activity. It can be viewed collectively as a rare landscape shaped by human engagement with a specific resource. It can give us insights into important aspects of how they exploited and used natural resources (Heldal, 2009) through several decades or centuries.

Traditionally the functional connectivity of landscapes (Scales and Scaletool, 2010) of the region was enabled through *Kere* (tanks) and *Bette* (hills) occurring at multiple spatial scales. However, the contemporary open-cast stone quarry hills (Figure 2) found in the peri-urban Bangalore have been extensively quarried for granite stone. The devastating scale of stone mining activity has caused disarrays in its flows of water, physical terrain conditions, flora and fauna and to the life in adjoining villages. It developed new patches of squatter settlements and life around these quarries made by the migrant population from the nearby towns and villages for work and livelihood. However, following a Supreme Court order on Feb 27, 2012 all stone crushing units and quarrying activities have been closed in Karnataka. The study landscape of Bettahalasur quarry, in the outskirts of North Bangalore, presents vivid pictures of these largescale mining in the region and that of the political rescaling processes in the past six to seven decades.

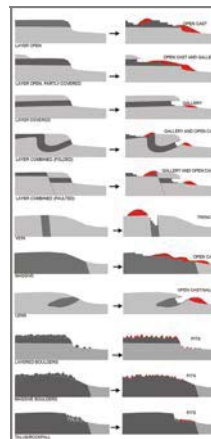


Figure 2. Various geological and morphological situations of stone resources and the resulting quarry landscapes. Stone resource=dark grey colour; spoil heaps=red colour. (Heldal, 2009)

The paper intends to examine the lack of planning strategies and awareness measures to have a symbiotic relation of quarry with the city. It proposes possibilities of integrating abused patches, to be regenerated as niches of life and liveable public space, within a newly invented built typologies and purpose. Through this integrated contextual response, we can create a place to visit, a place to learn from, a place to appreciate art (Bhat, 2016) and a living niche for various flora and fauna. The process of documenting the narratives of these quarry landscapes is illustrated in the following two sections of Landscape Vagaries and Socio-political Disarrays.

### ***The Landscape Vagaries***

“The sun the moon and the stars would have disappeared long ago, had they happened to be within the reach of predatory human hands” writes Havelock Ellis.

The study phase examines questions on what constitutes a ‘quarry site’ and do the varying site narratives - natural, socio economic and sensorial - matter in design process; could it be defined by its own qualities and quantities or by those of its neighbours and the expectations of the site. It adopts a bottom-up method of documentation using photo essays and transect studies; subsequently to a detailed environmental and social mapping of a selected area within the quarry. It intends to evolve a narrative of the site as a place rather than an object of study.

The Figure 3 illustrates the devastating extent of damage done to the landscape. It may be visualised from the material remains of the various processes involved which include traces of the extraction of rocks (tool marks), deposition of excess rock (spoil), tools, discarded products, work areas etc. Collectively, they tell us something about the processes involved in the selection of stone to be quarried, the production of it, the logistics related to its transportation and the social context and organisation related to sustaining the people involved in the quarrying. (Heldal, 2009)



Figure 3. The numbers representing devastating scale of stone mining happened at Bettahalasur Bangalore

The site-walk explorations are celebrated, as a visual memory, through a curated photo essay exhibition (Figure 4) on “THE QUARRY scapes” in the wider geography of the city. The subsequent site surveys, technical workshop on site planning and site analysis reveal a detailed visual and physical survey and analysis of the inactive quarry chosen for the design exploration.



Figure 4. The Photo Essay – Quarry Scapes at Bettahalasur Bangalore



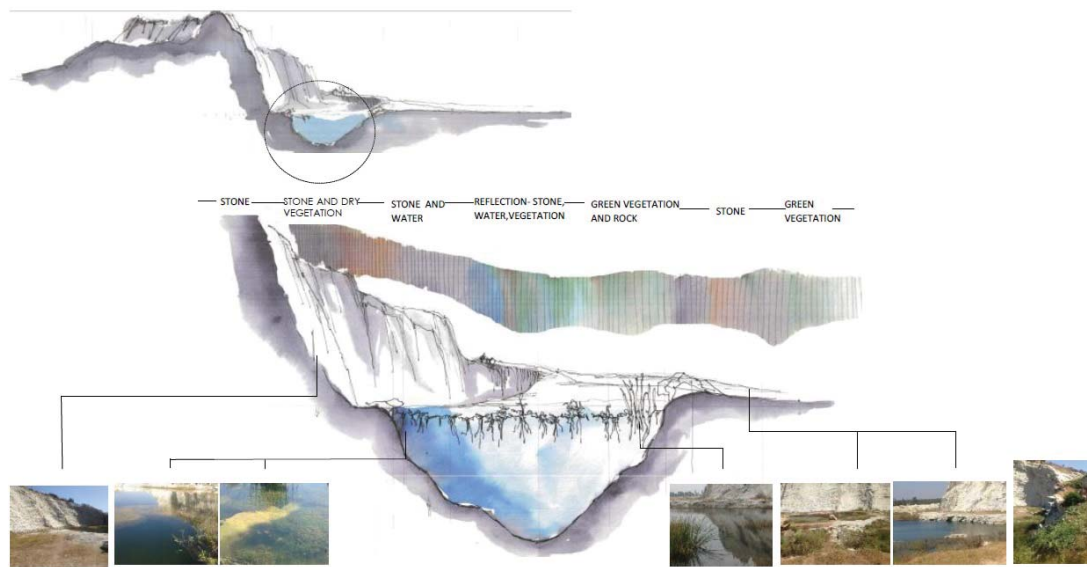


Figure 5. Transect Study 1 –Bettahalasur Bangalore

The site-transect studies (Figure 5 and 6) - cross sections through specific resources or experiences contained within the site - illustrate the location and distribution of resources. The resources ranged across various aspects - from natural, visual, socio-political, perceptual, everyday tactics, to experiential dimensions. It allowed identifying the constraints, opportunities, conflicts and also characteristics of the place; understanding appropriations, negotiations and conflicts at the boundaries. It thus, enabled to draw conclusions on the natural, behavioural and sensorial structure of the site. These diagrams are subsequently used to initiate structural analysis of linkages, transitions, patterns and interrelationships of people activities and different ecological zones along the transect.

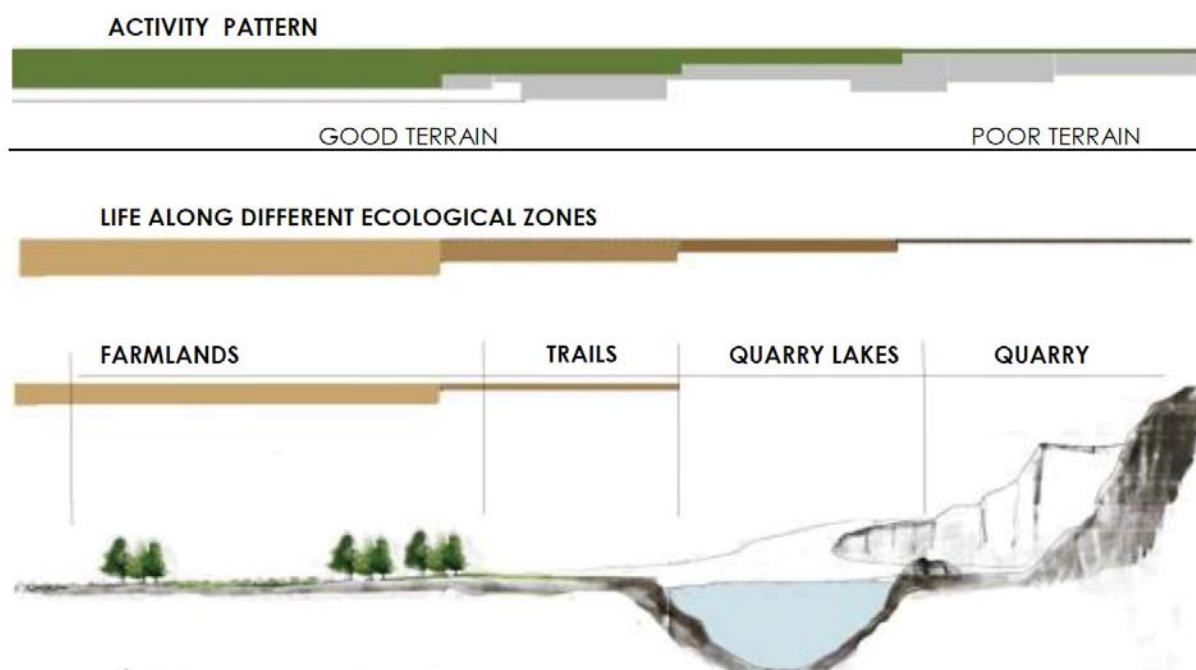


Figure 6. Transect Study 2 –Bettahalasur Bangalore

### ***The Socio-political Disarrays***

“Wandering on the rocks of the Bettahalasur granite quarry off Bangalore, I found this practically naked urchin following me, bursting with curiosity. Pre-focusing and setting the camera, I swiftly turned around and pressed the release before the subject became aware of what I was doing. In an instant everything changed and a few following shots missed the decisive moment and flopped. The hair makes people think it is a girl. It is in fact a boy with unkept hair. This picture was used by the United Nations, as it shows utter happiness in the midst of poverty. writes C Rajagopal in *Line of Light* Page 34 - *Joie de Vivre* 1974 (Rajagopal, 2003) (Figure 7)



Figure 7. ‘Joie de Vivre’ photographed by Rajagopal C in 1974 (Rajagopal, 2003)

The flux of migrants from the nearby towns and villages created new patches of squatter settlements and life, around these quarries. However, the Supreme Court order on Feb 27, 2012 closed down all stone crushing units and quarrying activities. It changed the life patterns in these landscapes drastically; it ordered all minor mineral quarries to take clearance from MoEF (Ministry of Environment and Forest) to continue mining activities. While Karnataka’s 1200 granite processing units have a combined capacity to process five lakh cubic metres of dimensional granite blocks, they currently process only about 50% of its capacity. Of which 80% of the granite gets imported from other states such as Rajasthan, Andra Pradesh, Telangana, Odisha and Tamil Nadu. (Govind, 2016)

The Karnataka State Pollution Control Board (KSPCB) however, submitted a petition in the High Court of Karnataka recently in this regard and the cabinet had subsequently requested amendments to the Karnataka Regulation of Stone Crushers Act, 2011, to relax stringent norms imposed on stone crushing units challenging the permission for stone crushing units near residential zones and renewal of leases. (Reporter, 2012) These political decisions have brought the quarry landscapes and the life linked to it to a stand-still, handing over the complete control and surveillance powers to the Mining and Geology Department of the State. Subsequently, several quarries have been taken over by the State as land-fill sites or for the development of public amenities such as Bus Stops etc. Development of private gated communities are also rampant in several of these quarry landscapes.

The film production, as part of the ethnographic study, illustrates the life around the quarries through conversations with three women from the quarry; Raseema Beevi of M S Palya quarry, Eswaramma and Muniyamma of Bettahalasur quarry. (Suseelan, 2016) The former laments over the lost glory of their lives, after the State took over the quarry land; whereas Eeswaramma lives in the present with her material possessions. However, Muniamma who earns a living from the drip irrigated farm, using the harvested water from the quarry, lends a ray of hope to this silent abandoned landscape.

Quarrying has been continuing illegally, even after the Mining and Geology Department stopped issuing the permits; illegal activities continues under the pretext of



deemed licensed owners at Bettahalasur, the study area. It is 117 acres of government land adjacent to National Highway-7 near Bangalore International Airport. The revised master plan 2016 for Bangalore indicates the Bettahalasur quarry site and its immediate surrounding as green land but there is no strict application of proposed land use plan as we can see the illegal encroachment adjacent to the National Highway-7. (Bhat, 2016)

### ***The Structure of the Site – Sensorial, Natural and Socio-economic***

A detailed analysis of the quarry site within various variables has been done – contour analysis, morphological evolution, settlement analysis to draw conclusion on site structure. A summary of the same is illustrated below. (Figure 8-16)

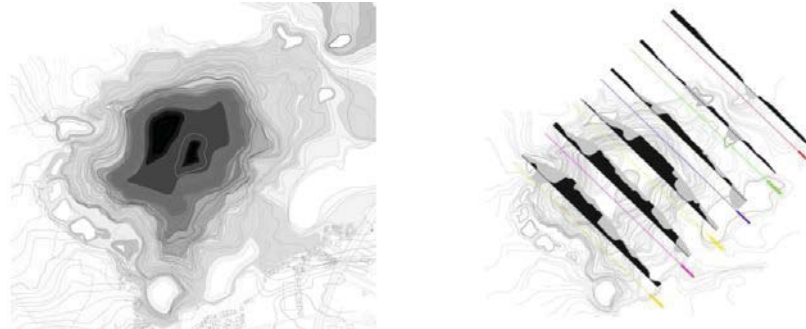


Figure 8. Quarry Contour Analysis –Bettahalasur Bangalore

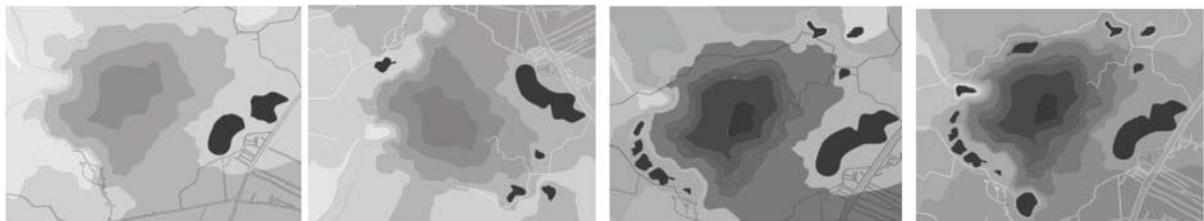


Figure 9. Quarry Morphological Evolution –Bettahalasur Bangalore

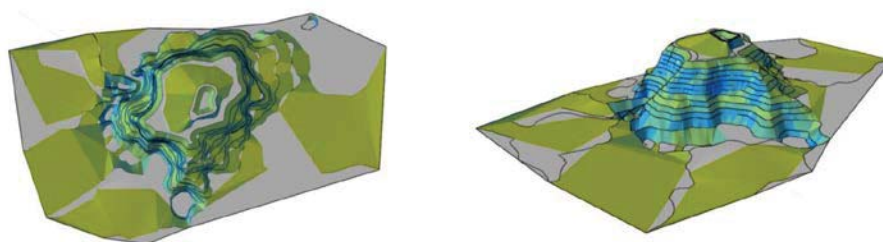


Figure 10. Quarry Contour Analysis –Bettahalasur Bangalore

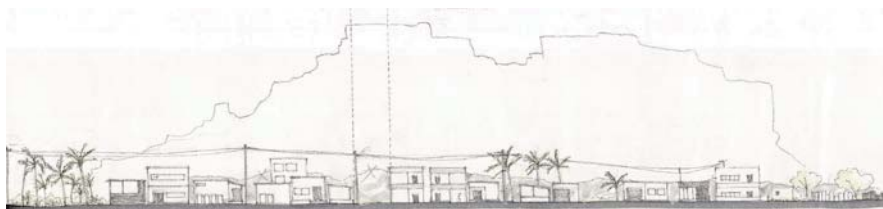


Figure 11. Quarry Settlement–Bettahalasur Bangalore



Figure 12. Quarry Network Analysis –Bettahalasur Bangalore



Figure 13. Quarry Activity Routes –Bettahalasur Bangalore

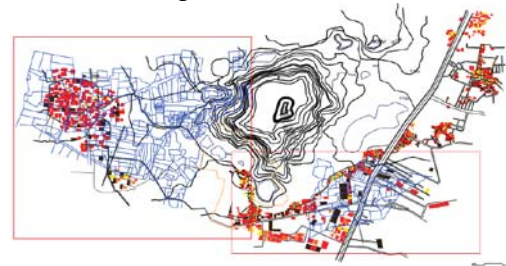


Figure 14. Settlement Analysis

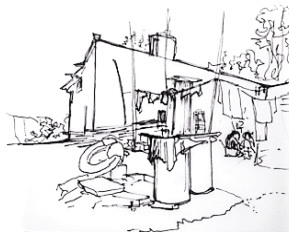


Figure 15. Settlement Analysis –Bettahalasur Bangalore

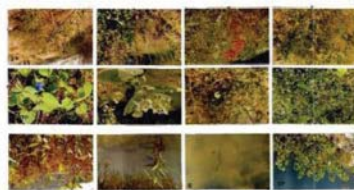
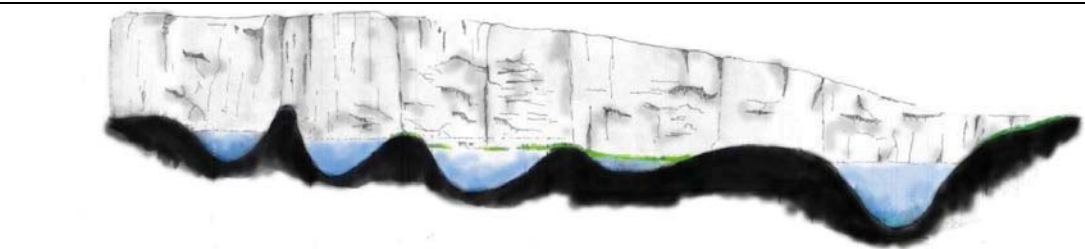


Figure 16. Vegetation Analysis –Bettahalasur Bangalore

## Design Approach – A Paradigm Shift

Ecosystems evolve over time and space as an outcome of dynamic interactions between socio-economic and biophysical processes operating over multiple scales. The ecological resilience of these systems depends on the degree to which they tolerate alteration before reorganizing around a new set of structures and processes. (Alberti & Marzluff, 2004) Drawing on the preliminary results of the relationships between these interactions it is observed that the surface water runoff of the quarry landscape has been severely disrupted due to terrain alterations and the natural habitats have been eroded due to heavy mining; leaving both the systems increasingly vulnerable and intolerant for habitation. The limited capacity of the prevailing conventions of design process, to respond to the scale of ecological crisis, has demanded a paradigm shift in the design approach. It therefore, proposes an ecological approach of design.

### *An Ecological Approach to Design*

The proposed ecological paradigm, to regenerate these landscapes, hypothesises to link human activity and ecosystem functions; it is critiqued for its artful dialogue with the site narratives and examine questions on design of spaces for social and intellectual exchange and the identity of the campus. The explorations are encouraged to evolve a campus site plan and detailed design, engaged with the natural, behavioural and sensorial structures of the site.



Figure 17. The Art of Site Planning –Bettahalasur Bangalore

### *The Art of Site Planning – towards an ecological succession*

The photo essay has been able to capture the signs of ecological succession in the quarry. The cue furthers thoughts in strengthening this process in the design. The growth of succulents in stone crevices, fishes in the trapped water of the quarry and the presence of Cormorant birds have fostered to identify the meaningful association of the campus of Centre of Environmental Education India with the quarry. The campus promotes the research for ecological studies and outreach programs for the revival of displaced agricultural and water practices in the region.



Harnessing water and correcting the altered water network are hypothesised as fundamental to site regeneration tactics. The idea is enhanced by reimagining architecture as a medium to harvest and reorganise water structure of the site; thus, to engage an artful dialogue with the site narratives. It proposes to connect the discontinuities of the site by identifying two public nodes; one at the existing neighbourhood as a public front and the other at the abused edge of the stone quarry as a bio diversity study hub of the institute. The rest of the site is left as agriculture and regeneration zones, thus limiting the movement of the public to the water edge alone. (Figure 17)

### *Integrated Built Typologies*

The design approach examines how architecture could be meditated as an interface of various datum of site concerns, functional priorities and the idea of an institution. It intends to develop the rationale of built-typology and material decisions. The project unravels the strong idea of an ecological approach, integrating campus site planning and its architecture as a way to protect the site; such as erosion control, water harvesting structures etc.

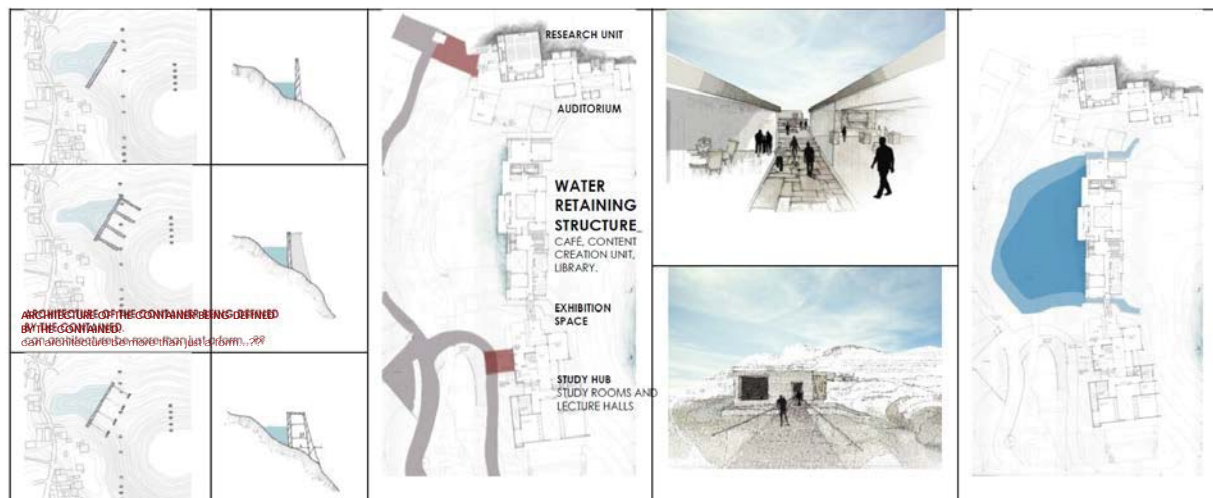


Figure 18. Design Demonstration – Bettahalasur Bangalore

The design prototype evolves from a line drawn in site (Figure 18) to dam water; as the primary site concern is to reorganise the disturbed water flows within the quarry. The multiple buttresses bolster the wall to evolve as a system to hold water. However, this novice attempt eventually develops into a bridge building to connect the disconnected quarry to the community space across. The integration of an infrastructure element in site with a functional integration of building results in a new built typology. The questions raised here are, can architecture be more than just a form? could the encounters of architecture with the challenges of an abused landscape initiate reimagining hybrid built typologies?

A chosen design module is tested for comparisons of different materials and structural systems to develop the design rationale. The development of new built typology prototypes and wall assemblies at the interface of functional spaces and quarry landscape reconstructions, illustrates a series of strategies and practices that may integrate the quarry with the built environment. Hence, the design demonstrates, in detail a built structure which works both as a hydraulic structure and a building which houses a public function connecting the public squares within the campus of Centre for Environmental Education (CEE) India.

## Conclusion

Like quarries, there are a host of degraded ecological systems resulting from human activity. The challenges that they pose to contemporary design are confounded by multiple issues. These ambivalent conditions may not get addressed by optimising design in isolation. The paper proposes that an integrated approach to design thinking, linking ecological regeneration and building design is necessary to have a sustainable development. The new built typologies need to perform functions beyond aesthetical, utilitarian or public space design. The paper thus explores how architecture and built typologies could bridge the new environmental requirements such as harvesting water, mediating connectivity and enhancing environmental sustainability.

## References

- Alberti, M. & Marzluff, J. M., (2004). Ecological resilience in urban ecosystems: Linking. *Urban Ecosystems*, Volume 7, p. 241–265.
- Allen, S., (2010). Field Conditions. In: K. A. Sykes, ed. *Constructing a New Agenda: Architectural Theory 1993-2009*. New York: Princeton Architectural Press.
- Analytical Diagrams-B Arch 2013 Batch, (2016). *Institutional Collective: Campus Design Studio Journal*. Bangalore: R V College of Architecture.
- Ashihara, Y., (1970). *Exterior Design in Architecture*. NY: Van Nostrand Reinhold Company.
- Bhat, S., (2016). *Adaptive Use of Quarry Site in Urban context*, Bangalore: BMS College of Engineering.
- Burns, C. J. & Kahn, A., (2005). *Site Matters: Design Concepts, Histories and Strategies*. New York and London: Routledge.
- Clarke, H. R. & Michael, P., (2012). *Precedents in Architecture: Analytical Diagrams, Formative Ideas and Partis*. Fourth ed. New Jersey: John Wiley & Sons, Inc.
- Govind, R., (2016). *Karnataka No More the Leader in Granite Trade*. Bangalore: The Hindu (Newspaper); 02 Feb 2016.
- Hangal, S., 2016. *Design Portfolio - A Report of Semester VI Architectural Design Studio*. Bangalore, India: R V College of Architecture.
- Heldal, T., (2009). Constructing a quarry landscape from empirical data. General perspectives and a case study at the Aswan West Bank, Egypt. In: N. Abu-Jaber , E. G. Bloxam, P. Degryse & T. Heldal, eds. *QuarryScapes: ancient stone quarry landscapes in the Eastern Mediterranean*. Norwat: Geological Survey of Norway Special Publication-12, pp. 125-153.
- Kanvinde, A. & Miller, J. H., (1969). *Campus Design in India: Experience of a Developing Nation*. USA: Jostans American Year Book Co.
- Lynch, K. & Hack, G., (1984). *Site Planning*. s.l.:Library of Congress Cataloguing.
- Maki, F., (1964). *Investigations in Collective Form*. St Louis: The School of Architecture, Washington University.
- Marcus, C. C. & Wischemann, T., (1998). Campus Outdoor Spaces. In: C. C. Marcus & F. Carolyn, eds. *People Places: Design Guidelines for Urban Open Space*. Second ed. New York: John Wiley & Sons, Inc, pp. 175-208.
- McHarg, I. L., (1992). *Design with Nature*. New York: John Wiley & Sons Inc.
- Morrison, H. H. +. A. a., (2013). *Architectural Design Entry Competition for Nalanda University Campus: Master Plan and Phase1 Construction*, s.l.: architexturez.net.
- Rajagopal, C., (2003). Joie de Vivre in 1974. In: C. Rajagopal, ed. s.l.:Simova Education and Research, 2003, p. 34.
- Reporter, S., (2012). *All stone quarries closed: KSPCB*. Bangalore: Deccan Herald; 3 Jul 2012.
- Scales and Scaletool, (2010). *Differences between structural and functional connectivity*. [Online] Available at: <http://scales.ckff.si/scaletool/?menu=4&submenu=0> [Accessed 01 October 2017].
- Suseelan, A., (2016). *Journey to Quarry Scapes (Short Film)*. [Art] (R V College of Architecture).
- Thomas, H. R. & RLA, (2009). *Site Planning and Design Handbook*. Second ed. New York: Mc Graw Hill.
- Zimmerman, A., (2006). *Integrated Design Process Guide*. s.l.:Canada Mortgage and Housing Corporation.

# Impact of integrating renewable energy on the form of the city “wind corridor as an approach for sustainable urban communities”

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**Abstract:** The growing global interest on reducing energy consumption has increased public awareness of raising energy efficiency on different urban levels and using more benign forms of energy. This paper studies the possible impact of using renewable energy and strategies to raise the energy efficiency on urban design level in hot climate regions as a new vision for a sustainable urban community in a trial to minimize carbon emissions results from cities to reduce pollution and enhance the environment, this was achieved by creating wind corridor inside the city by using urban structure to adapt wind to flow in a certain path and increase its speed that suit generating power from wind potentials after installing small scale wind turbine in appropriate locations inside the city, also this concept will lead to a better wind ventilation. Finally a new Egyptian city was chosen based on its renewable energy potentials then evaluating and editing its master plan and implement wind corridor strategies inside it to be more sustainable.

**Keywords:** Sustainable urban communities, Renewable energy, Energy saving, wind corridor.

## Introduction

Our planet is witnessing exciting times: The world population is booming like never before while the third world economies are growing at an accelerating pace, consequently a steady migration from rural to urban areas is occurred, as more people now seeking higher standards of living, it is increasingly challenging to supply them with adequate food, potable water, clean air, modern infrastructure and affordable energy, all while preserving the environment (Mostafavi, M., 2010).

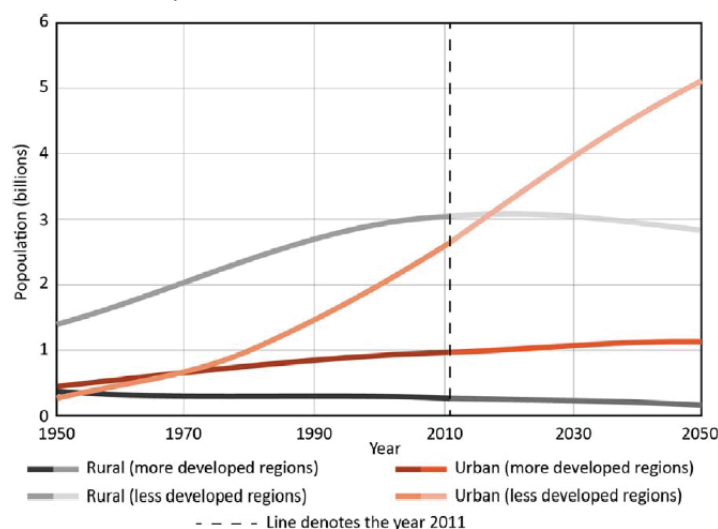


Figure 1. World population in urban and rural areas. The dotted line denotes the year 2011.

As population living in cities only in less developed regions could double in the next half century which will lead to large numbers of environmental problems, one of these problems is that the energy consumption per person will increase (UN, 2012) so more energy will be produced, and relaying mainly on fossil fuels to apply this new huge demand will lead to produce more CO<sub>2</sub> gas in the atmosphere which will case raising of earth temperature in a rapid rate and increasing pollution.



## **Climate change and the start of the international perception of the environmental issue**

Acid rain phenomenon was the reason to start a global interest in the issue of the environment and the appearance of the of sustainable development definition in 1971.

Also, the appearance of the scientific reports issued by the governmental Committee on Climate Change has raised a wide range of reactions that Earth's temperature had already raised by 0.75 °C in the last century and confirmed that by the year 2050 the it is estimated to rise by 2 °C, but also this increase could occur by the year 2035, as a result of the rising temperature (UN Report, 2015).

The international perception of the environmental issue appeared in many scientific reports that raised a wide range of reactions and called for International conferences that aimed to reach to a global agreement on the reduction of climate change by:

- Reducing greenhouse gas concentrations in the atmosphere.
- Came out with obligations on developed countries to reduce the current emissions.

## **Sustainable development could be the solution**

As this growing awareness of the environmental issue increase, many countries started to establish their own rating system aiming to build new communities or to improve the existing ones in such a way to raise their efficiency and minimize their impact on the environment during construction, operation and final demolition phases (*Y. Toparlar, 2017*).

## **Sustainable Renewable energy**

Electricity from fossil fuels such as oil, coal and natural gas negatively affect the environment at each step from production till consumption, electricity generated using sources other than fossil fuel reduces the environmental impacts and as a rule of thumb the better the energy performance of a building, the fewer greenhouse gases are emitted (LEED BD+C V4, 2013)

It's worth to mention that energy related credits in LEED version 4 account for almost 2/3 of all available points (LEED BD+C V4, 2013), this leads us to consider that the major shift in the vision of sustainable cities is the potential of buildings to produce energy from renewable resources (Azizi. M, Javanmardi. K, 2016), this will entail a whole host of solutions that will make cities more sustainable.

## **Wind energy**

Winds are driven by the uneven absorption of solar energy by the surface of the earth that has been converted by a huge global thermal engine to the kinetic energy of the moving air (Kelly, E.J. 1987).

Wind turbines are available in a wide range of sizes from rotor diameters of less than a meter to very large wind turbines with rotor diameters greater than 100 meters with a capacity of several megawatts, but there are two things worth noting when generating power from wind turbine is required:

- An increase in the rotor diameter of a wind turbine will result in a greater than proportional change in rated power.
- An increase in wind speed will result in a greater than proportional change in the generated power, the generated power is proportional to the cube of the wind speed, and hence a doubling of wind speed will result in a roughly eight-time increase in power output.

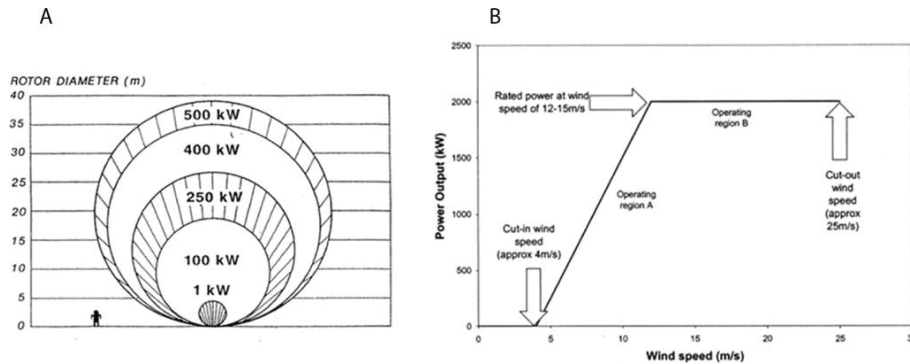


Figure 2. (A) Rotor diameter versus output capacity, (B) Representation of wind turbine operation regime.

### Combination strategy and the difference between “Old Greens” and “New Greens”.

One of the major difficulties that we faced in the past in order to maximize our dependence on renewable energy is that a huge land area is required to generate power from renewable resources from a centralized infrastructure investment outside the city (Old Greens concept), but now this vision had been changed as the new concept of sustainable cities (New Greens concept) is that the city itself could generate considerable portion of its power from renewable resources without the need for this huge land area (as if this area is merged inside the city) by using urban form (structure) to enhance wind behaviour in the urban areas and installing wind turbines wherever appropriate (on buildings elevations, roofs and in the streets... etc.), which will result in a great economic, social and environmental impacts such as:

- 1- Reducing land area that was dedicated for energy production.
- 2- No need for long electric cables since the location of producing and consuming energy is the same, which has a great benefit on both environmental and economic issue.
- 3- Enhance public awareness about the environmental issues by creating a direct contact between them and the renewable energy generators which will also encourage them to reduce their electrical consumption.

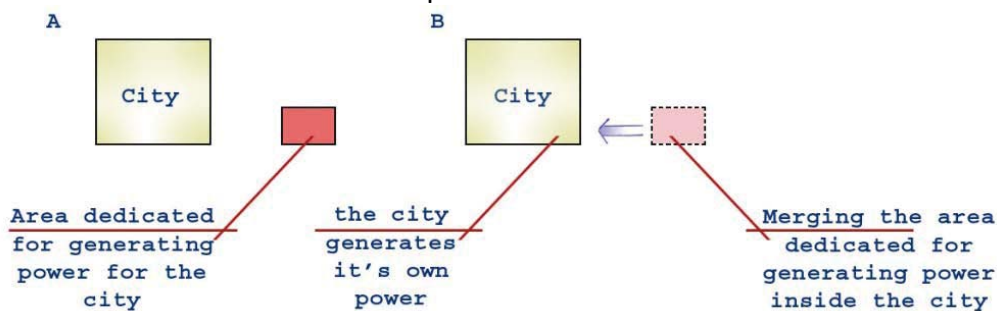


Figure 3. Combination strategy (A) Old greens concept, (B) New greens concept.

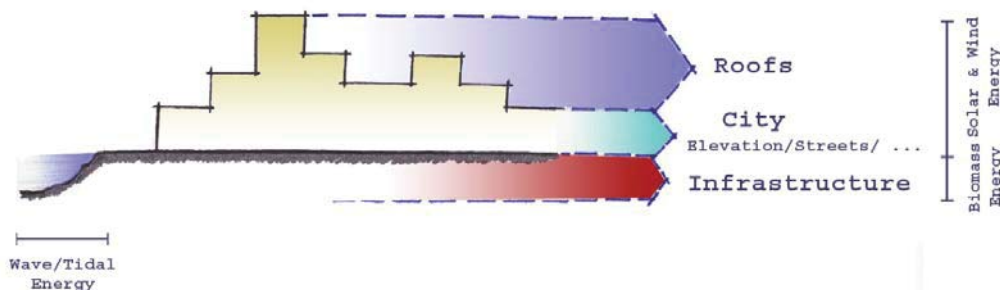


Figure 4. Conceptual section showing locations of expected generated renewable energy inside the city.

Although following new greens concept could be a better approach for generating power from renewable resources inside the city, but this concept may also be enhanced by using old greens one to reduce relaying on energy generated from fossil fuels and its accompanying carbon emissions.

In addition, enhancing wind behaviour in urban areas results in purification of air pollution from roads, better air circulation, remove heat from urban areas and reduce urban heat island effect in hot climate regions.

### Wind & form of the city – Designing wind corridors

Designing wind corridors to enhance urban natural ventilation and generating power from wind turbines inside the city is a new important approach that should be taken into consideration when designing a new city (Liu Sumei, 2014).

Recognizing essential canals of air flow then propose design interventions on the urban forms that led to correct routes in order to generate power from wind resources (by consider increasing buildings heights, adjusting buildings orientation, increasing spacing between buildings, widening of adjunct roads, adjusting percentage of wall openings in the buildings, determine the exact location to install wind turbines, determine the size and type of wind turbines) and finally consider these elements in the future development plans to not be obstructed could be the methodology to design wind corridor inside the city.

Computational fluid dynamics (CFD) such as ANSYS Fluent came out that building geometries have a strong impact on the wind flow patterns on urban level and could be utilized for the purposes of predicting, testing and finally modifications and adjustments of urban forms to enhance wind behaviour and creating wind corridors in and around urban blocks and streets (Allegrini, J. Carmeliet, J. 2017).

### Studying Sultan Hassan and Rifai mosques in Cairo

The previous architectural and urban items appeared in this example that showed a rough estimation for increasing wind speed in the intermediate corridor between the two huge mosques by around 40% than the surroundings (Abdel Aziz, T. Elmassah, O. July 2012).

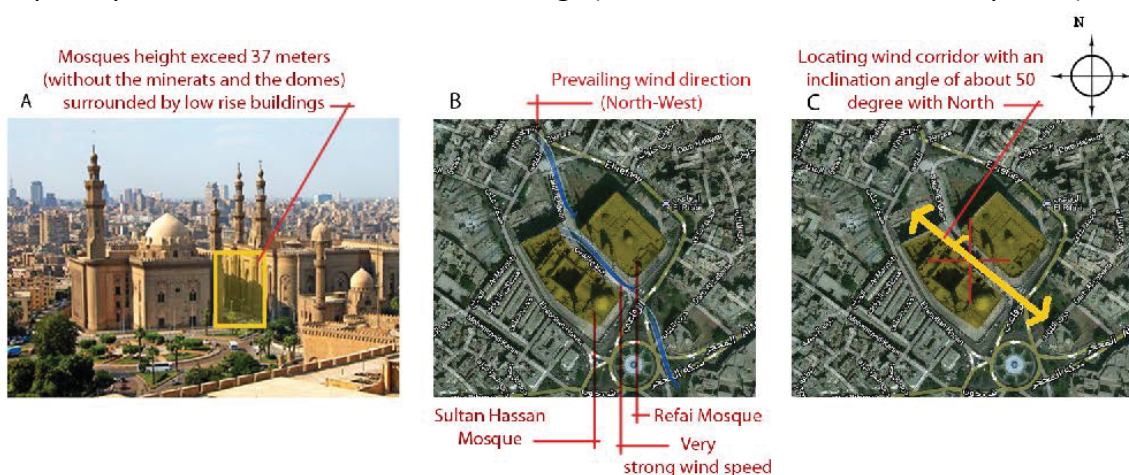


Figure 5. Wind analysis between Sultan Hassan & Rifai Mosques.

### Studying wind corridor in Masdar city

The concept of wind corridor appeared previously in Masdar city through a daytime / night-time wind study, the designer orient the wind to flow in a certain path inside the city for the

purpose of ventilation which result in reducing energy needs for mechanical cooling loads consequently reducing energy demands and total CO<sub>2</sub> emissions inside the city (Foster + partners. 2014).

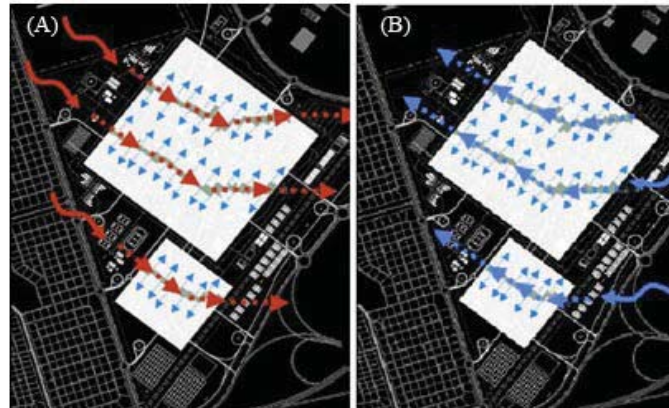


Figure 6. Masdar city indicates the use of wind corridor concept for the purpose of enhancing ventilation inside the city, (a) Day-time wind study (b) Night-time wind study.

### ***Studying wind behaviour in a residential community in Tianjin, China***

The analysis using ANSYS Fluent software showed that wind speed and pressure difference increases when angle between building and wind direction decrease, The ventilation potential become better and better from case I to case III when the angle between building and wind direction become smaller and smaller (Liu Sumei, et al, 2014), this was used in this example to enhance natural ventilation potentials inside the urban community.

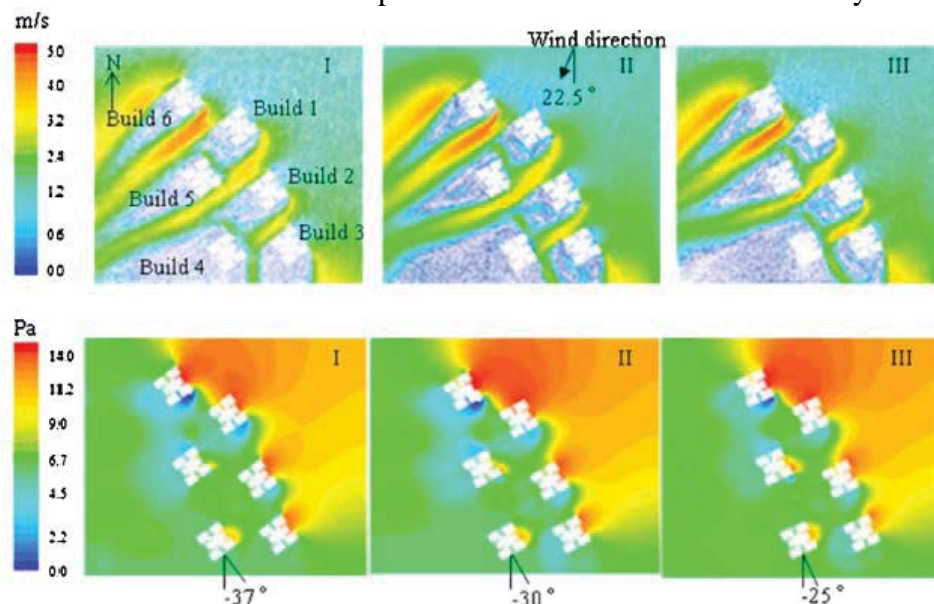


Figure 7. Air velocity and pressure distribution around the buildings of four different building angles using ANSYS Fluent 12.1 (at 1.5 m above the floor).

### ***A conceptual vision for wind corridor strategy***

Creating wind corridor inside the city to adapt wind to flow in a certain path that suit generating power through nodes by increasing densities (buildings, trees ... etc) before the node (to increase the quantity of wind that flows to generate power) and decrease it after the node (to pull in more wind for the next node), also this concept will lead to a better wind ventilation for the city (Cheshmehzangi. Ali, Zhu. Yan, 2017).



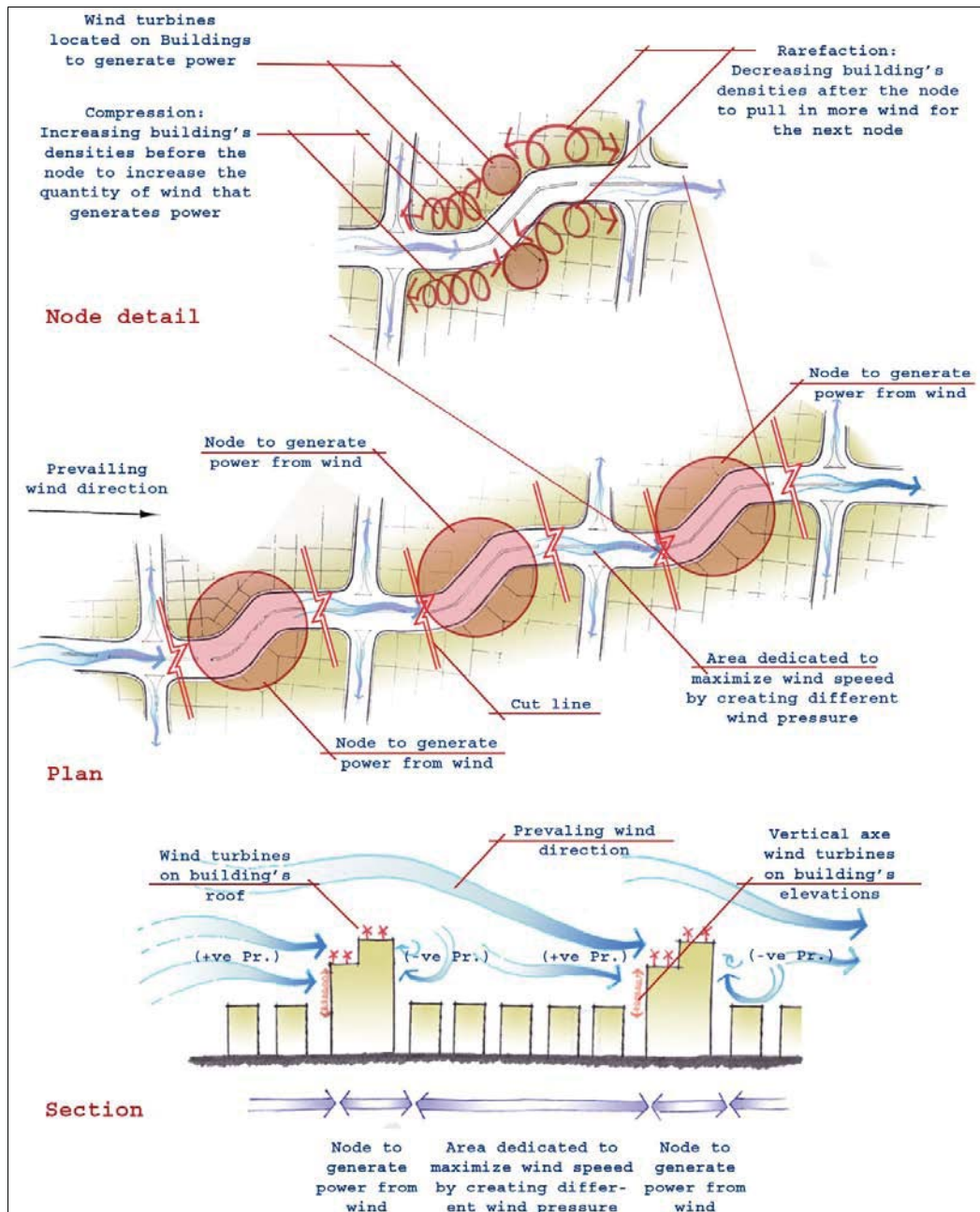


Figure 8. shows a conceptual vision for the wind corridor strategy including a conceptual plan and section in the corridor (street in this case), beside a node detail showing building's densities before and after the node.

### Case study – Al -Zafrana city – Egypt:

Al-Zafrana is a new Egyptian city located on the red sea, its location is unique due to its high average wind speed which is 9.0 m/s and is considered as one of the highest wind regions in Egypt.

### Ecological studies

#### Wind

- Northern and North-Western wind are generally the prevailing wind direction throughout the year, with an annual average rate of 26.6% for North wind and 41.3% for North West wind while the percentage of blowing wind from other directions are considered to be very low.

- Wind from Northern and North-Western direction are moderate and are required to penetrate the buildings blocks to ventilate architectural and urban spaces with minimal barrier to minimize heat stress on the human body in summer.

#### *Solar radiation and clouds*

- Clouds over the city are few, they cover about quarter the sky in the winter, while totally disappear in summer (NREA. 2007).

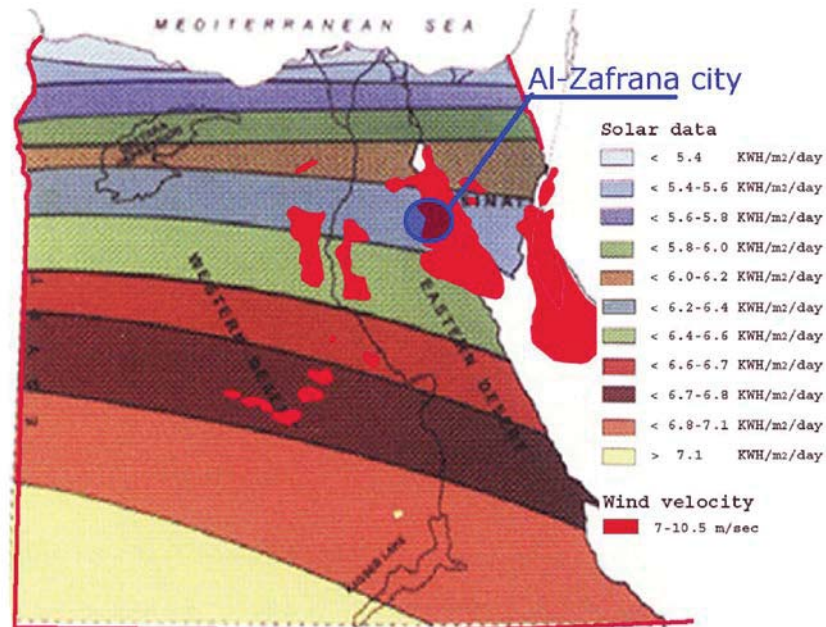


Figure 9. Location of Al-Zafrana city in Egypt, showing wind potentials and solar intensity.

#### ***The governmental general plan for Al-Zafrana***

The general plan consists of 3 nuclei depends on the interaction between environmental, economical and demographic elements to form one urban fabric and linking the major planning units (district - neighborhood - residential area) with the surrounded streets network in order to achieve the environmental planning objectives.

#### ***The governmental general plan for Al-Zafrana***

The master plan report recommended that the orientation of the main urban planning blocks, buildings and urban spaces to be in the North East – South West direction to take the advantage of the North and North-West wind in minimizing heat loads inside the city as shown in Fig. 8 below. Besides considering sea breeze in buildings orientation attached to sea. Also, it ensures about the importance of providing shadows in public spaces to minimize summer heat loads (GOPP. 1997).



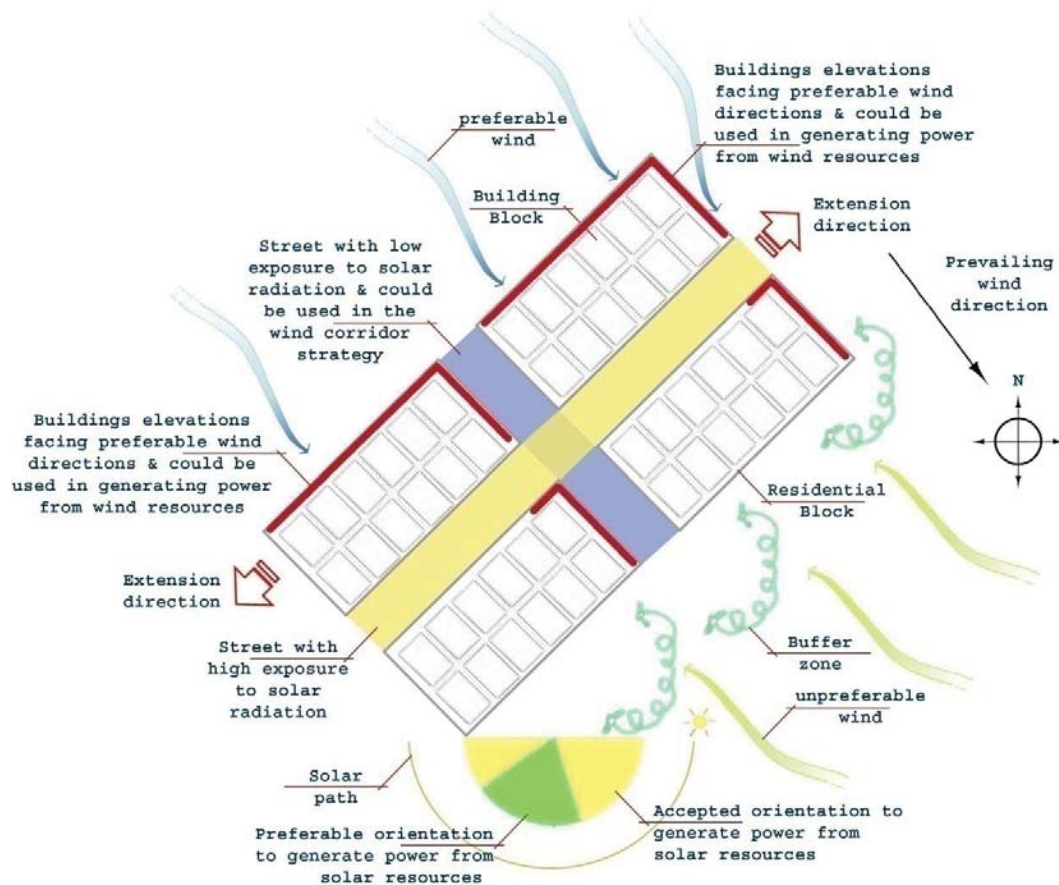


Figure 10. Analysis on the proposed orientation in the master plan report according to the GOPP.

But by locating urban planning blocks, residential blocks and urban spaces in the North West – South East direction as shown in Fig. 9 we could achieve the following:

- 1- High exposure to solar radiation will be in the shorter street while low exposure to solar radiation will be in the longer one; this will minimize heat island effect in the city, improve thermal comfort and raise its energy efficiency.
- 2- Increasing the potentials for generating wind power from renewable resources in the longer street that could be used by applying wind corridor strategy in it.
- 3- Increasing the percentage of buildings elevations that could be used in generating power from wind resources (wind nodes).
- 4- Increasing the percentage of buildings elevations facing preferable wind direction which will minimize mechanical cooling loads required in the city and consequently increasing its whole energy efficiency.
- 5- Minimize number of buildings exposed to un-preferred wind direction and also the required buffer zone area around the city.

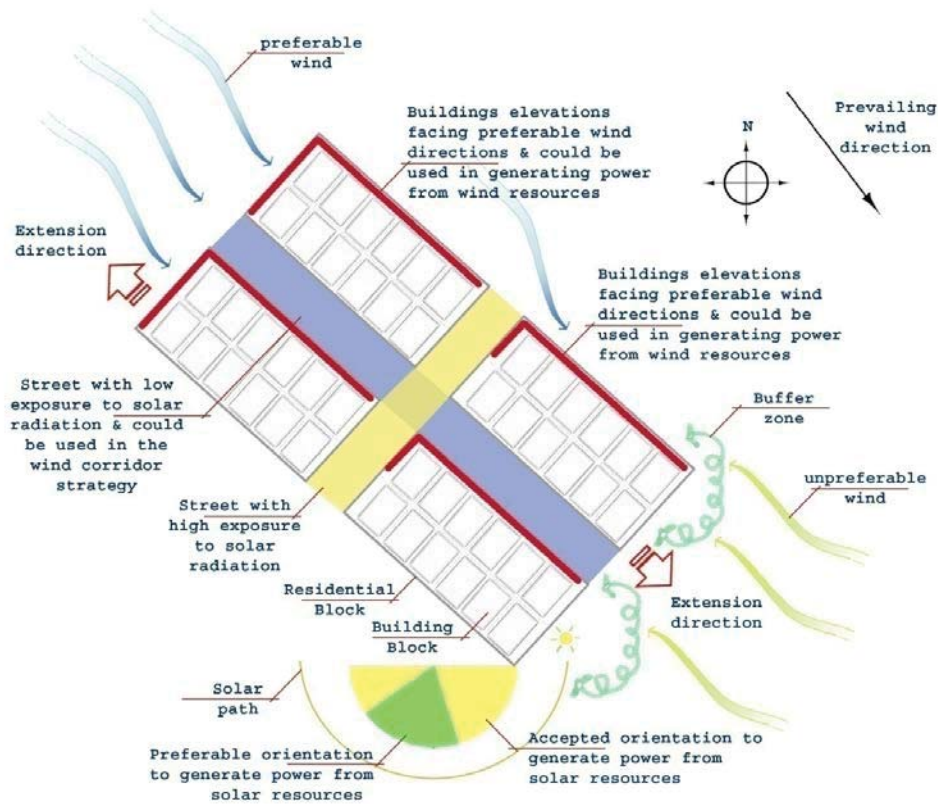


Figure 11. Analysis on the new proposed orientation according to the researcher.

### ***Modifications on the form of Al-Zafrana master plan according to the new design criteria***

Although the huge renewable energy potentials in the city due to it's distinguish location they don't exist as a strong parameter in the master plan report, so this section will try to represent the effect of considering energy efficiency strategies and renewable energies considerations on the form of three nuclei of the proposed general plan.

#### ***A- First nucleus***

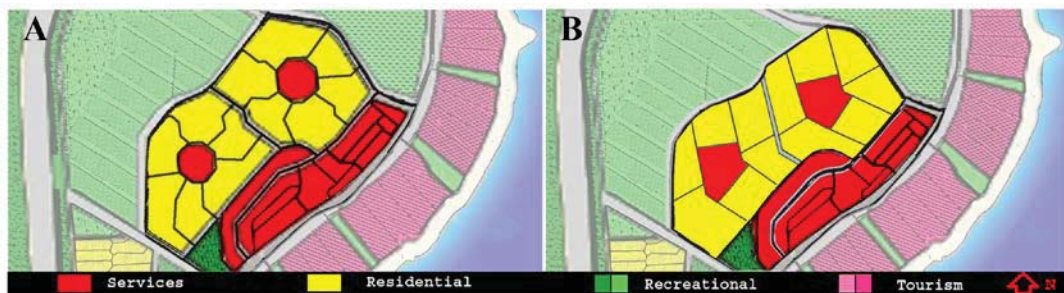


Figure 12. (A) Governmental General plan for the First nucleus of Al-Zafrana December 1997, (B) The proposed general plan from the researcher after considering energy efficiency strategies and renewable energies considerations on the form of the districts.

#### ***B- Second nucleus***

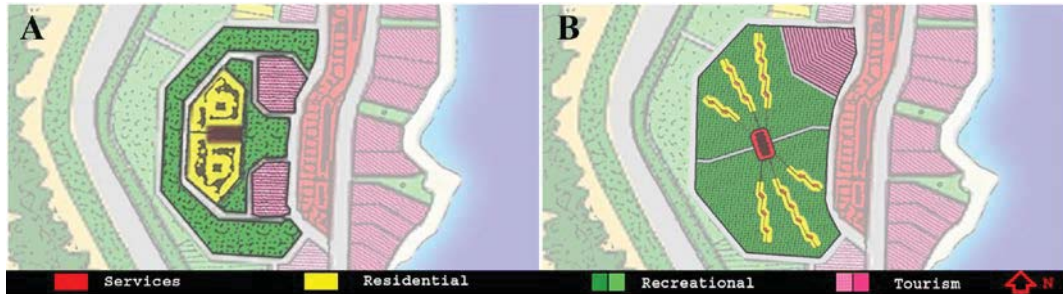


Figure 13. (A) Governmental General plan for First nucleus of Al-Zafrana December 1997, (B) The proposed general plan from the researcher after considering energy efficiency strategies and renewable energies considerations on the form of the districts.

### C- Third nucleus

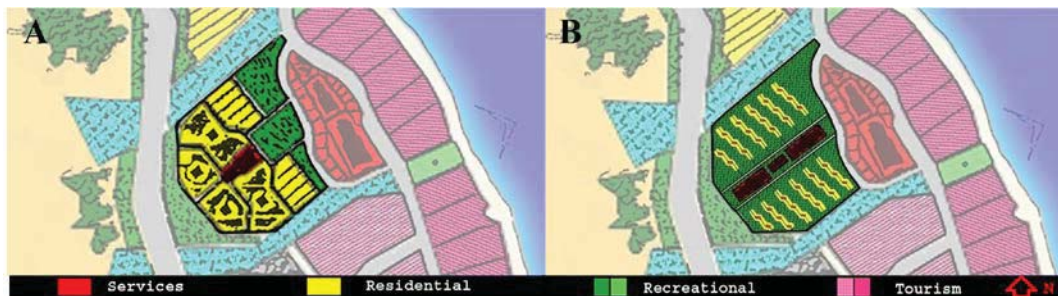


Figure 14. (A) Governmental General plan for First nucleus of Al-Zafrana December 1997, (B) The proposed general plan from the researcher after considering energy efficiency strategies and renewable energies considerations on the form of the districts.

### Explanation of the new modifications

- Preserve the average area of the nucleus.
- Breaking main street's directions to be North & North-West (prevailing wind direction) and South-East (sea breeze wind direction) to create wind corridors in order to minimize heating loads and creating nodes to generate power from wind inside the city, also these directions will minimize the solar exposure for streets inside the districts.
- Create a relatively high dense population zones in the wind nodes areas.
- Integrating landscape and recreational areas between residential land uses (in second and third nuclei).

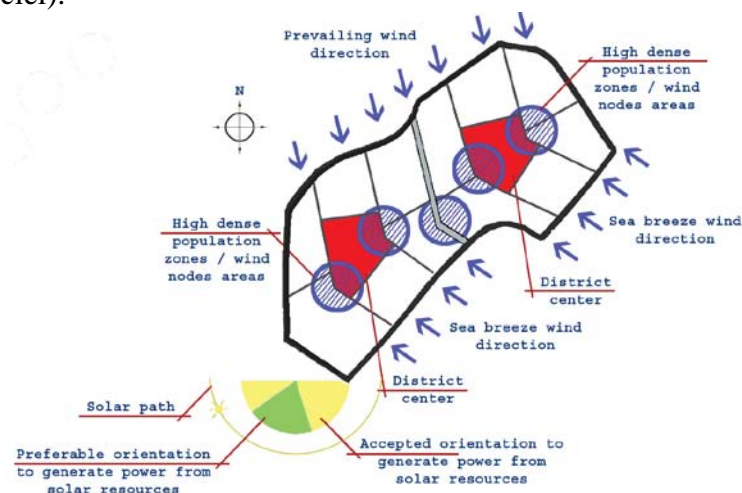


Figure 15. (A) Analysis on the modified first nucleus.



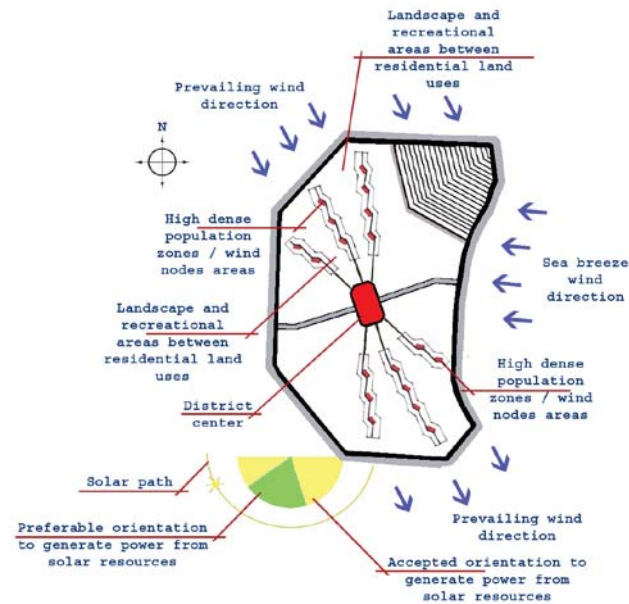


Figure 16. (A) Analysis on the modified second nucleus.

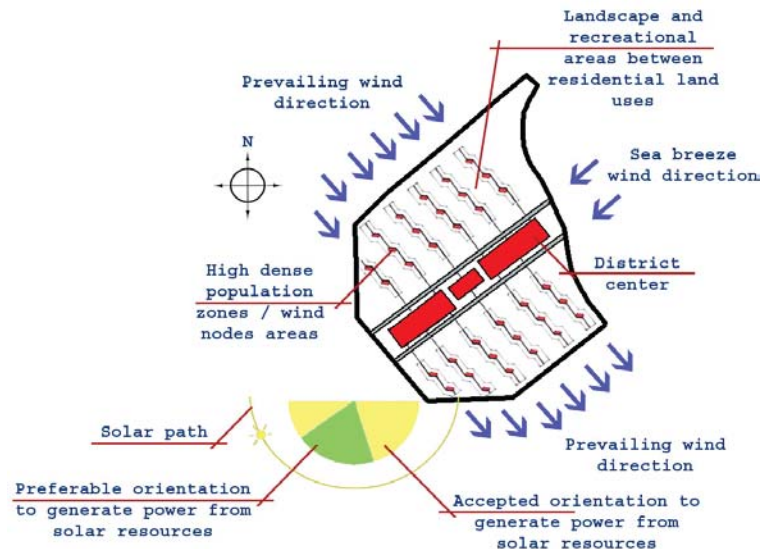


Figure 17. (A) Analysis on the modified third nucleus.

## Conclusion

- Integrating renewable energy nodes inside the city could be an energy efficient approach to achieve sustainability and has a direct impact on affecting the form of the city.
- Creating wind corridors inside the human settlements is an efficient environmental approach especially in hot climatic zones that result in enhancing natural ventilation and energy efficiency for buildings, minimize heat island effect, purification of air pollution from roads, creating relaxed conditions and also could be used for generating power from renewable resources.
- The designed wind corridors should be considered in future development plans and should not be obstructed by any construction elements.
- Providing green and open spaces will facilitate wind flow, resulting in the creation of more pressure difference in adjunct blocks.

- CFD could be used to develop a numerical model to design, test and evaluate wind corridor.
- Factors have direct impact in creating wind corridor:
  - Block heights, orientation and building spacing.
  - Width and orientation of adjunct streets.
  - Spaces with prevailing wind direction.

## References

- Abdel Aziz, T., Elmassah, O., (2012), *Could renewable energy affect the form of the city? Case study on wind energy considerations*. Terragreen 2012: Clean Energy Solutions for Sustainable Environment (CESSE). Energy Procedia Journal. Elsevier. Online version via Science Direct. 18. pp. 276–290.
- Allegrini, J. Carmeliet, J. (2017), *Coupled CFD and building energy simulations for studying the impacts of building height topology and buoyancy on local urban microclimates*, Urban Climate, Elsevier, Online version via Science Direct. 21, pp. 278-305.
- Arup, O., (2004), *Planning for renewable energy*, Queen's stationary office.
- As-Architecture Studio. (2009). *The Ecological city*. Paris. Silvana publishers.
- Azizi. M, Javanmardi. K, (2016), *The effects of urban block forms on the patterns of wind and natural ventilation*. International high - performance built environment conference – A sustainable Built Environment Conference 2016 Series (SBE16). iHBE 2016, Energy Procedia Journal. Elsevier. Online version via ScienceDirect. 180. pp. 541–549.
- Cheshmehzangi, Ali, Zhu. Yan, (2017), *Application of environmental performance analysis for urban design with Computational Fluid Dynamics (CFD) and EcoTect tools: The case of Cao Fei Dian eco-city, China*, International Journal of Sustainable Built Environment (2017), Energy Procedia Journal, Elsevier, Online version via Science Direct, 6, pp. 102–112.
- Foster + partners. 2014. website, <http://www.fosterandpartners.com>.
- GOPP. 1997. *General plan for Al-Zafarana-Report for the general urban development for Red sea region*. Egypt. El Ahram printers.
- Kelly. E, (1987), *Harvesting the air*, windmill pioneers in 12th century England, University of California, USA.
- Liu. Sumei. et al. (2014). *Coupled simulation of natural ventilation and daylighting for a residential community design, school of environmental science and engineering, Tianjin, China*, Energy and building, 68, pp. 686-695.
- Mostafavi, M., (2010). *Ecological urbanism why ecological urbanism? Why now*. Harvard University. Cambridge. Lars Muller publishers.
- New and Renewable Energy Agency (NREA). (2007). *Annual report*. El Ahram printers. Egypt.
- United Nations. 2012. *World Urbanization Prospects: The 2011 Revision*. New York.
- United Nations. 2015. *Adoption of Paris agreement - Proposal by the President*. Paris conference for climate change. FCCC. Paris. 2015.
- United States Green Building Council USGBC. (2013). *LEED reference guide for Green Building Design and Constriction*. Version 4. Washington DC. United States Green Building Council.
- Y. Toparlal, (June 2017), *A review on the CFD analysis of urban microclimate*, Renewable and Sustainable Energy Reviews, Elsevier, Online version via Science Direct, 80, pp. 1613-1640.



# Integrated Framework for Establishing Community Based Ecotourism, Case Study Egypt

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**Abstract:** Earlier in Egypt environmental protection and community participation wasn't the main concerns for traditional tourism, but nowadays engaging the community in managing ecotourism development becomes an essential target to grasp. It is noted that 93% of the Egyptian land is virgin desert areas with unbelievable combinations of biodiversity. Nevertheless, Eco lodges in Egypt face ongoing degradation and have an environmental negative impact on the present natural habitat, due to the lack of appropriate research and inadequate management strategy. The paper adopted a logical unified multidiscipline methodology (LUMD) through investigating the evolution of ecotourism, its participants, key considerations for ecotourism development at the community level, the GOs & NGOs role in promoting ecotourism, the industry demands for ecotourism, and finally the international principles & guidelines. The paper's main aim is to explore the prerequisites for an ecotourism management plan and how it contributes to the community based developments within the Egyptian context. The results present a developed integrated framework for managing ecotourism & involving the community in the development process. Accordingly the contributed framework is considered a pilot one that firstly combines the international guidelines and the concurrent local ones taking into consideration, how to reduce the threats, strength the opportunities, and assign the role of each of the participants & partners. It also target coping with the Egyptian eco-tourism nature and grantee running its development in a sustainable way that ensure resources conservation for the new generations, and community participation.

**Keywords:** ecotourism, community participation, environmental impact, degradation, sustainable development.

## Introduction

Over the last decades ecotourism has been growing rapidly. Yet, however ecotourism has the potential to build a positive social and environmental impacts, it can also leads to environmental damaging if not constructed properly (Wood, 2002). To recognize the global importance of ecotourism, the United Nations nominated year 2002 to be the "International Year of Ecotourism". The main goal of this day is to review the lessons learned in applying ecotourism, and to promote and identify forms of ecotourism that lead to critically guard for endangered ecosystems to share the activity benefits.

According to Travel, Communities & sustainable, 2013 eco-tourism is defined as public travelling to conservation and natural areas to participate in entertaining activities through emphasizing on preserving the land natural resources and improve wildlife, people, and culture welfare. In 2002 the United Nations World Tourism Organization has adopted the theme of promoting and enhancing ecotourism internationally (UNWTO, 2017). They released a report concluding the most significant approaches related to ecotourism, these approaches discussed the environmental protection, ecosystem conservation, sustainable development promotion, the poverty alleviation, and finally the ecotourism positive impact on biodiversity, conservation, and local heritage (Organization, 2017). Egypt has responded to this report by participating in UNWTO as a representative country that is planning to start developing in ecotourism field (Hassan & Denman, 2006). Although ecotourism in Egypt is considered as a recent development trend, but the related projects to this field has grown speedily since 2010, to reach 34% per year according to UNWTO statistics (Avraham, 2016). Since Egypt is still a developing country, so ecotourism are mainly supported from small and local tourism enterprise rather than the sustaining under a governmental strategy (Sanò,

Richards, & Medina, 2014). As the Egyptian government ecotourism strategy still till now in its early stage and not well regulated by concrete laws and legislation. (Tell el-Borg, 2014). Currently there are a lot of progressive integrated frameworks to guide the community based ecotourism all over the world, but in Egypt the community participation doesn't follow specific guidelines, it only depends on individual trials" (El-Barmelgy, 2005) which is an outdated manner that is exposed to time consuming, human errors , and of course does not guarantee precise management system. This leads us to the research aim to develop the existing Egyptian ecotourism guidelines to propose a new integrated framework through analysing internationally ones together with the current Egyptian strategy to finally reach a sustainable managing community based ecotourism framework. Nowadays the Egyptian tourism ministry is planning to adapt the sustainability standards of government strategic vision 2030, to apply it in Sharm El-Sheik as a start for Eco-green sustainable tourism (Egypt Tourism, 2000).

### **Ecotourism Different Aspects:**

To create a tourism development that sustained for a long time through a divergent balance between biodiversity conservation and economic development, this process is considered one of the hard task that ecotourism field is responsible about (Arsić, Nikolić, & Živković, 2017, Xu, Mingzhu, Bu, & Pan, 2017). Regarding to (UNWTO, 2017) ecotourism is not only an environmental protection but it is also considered as a primary income source in development countries like Egypt. (El-Barmelgy, 2005). Adding to previous fact, Hong & Yan, 2011 stated that ecotourism is one of the main systems that builds the green economy concept and respectively it adds to gross domestic product of concerned countries(El-Barmelgy, 2005). However integrating both aspects of human society and ecological biodiversity, are considered a tough job that needs a high level of understanding for both their needs. Yet these needs can be potted under the ecotourism basic principles which are (Wearing, 2011) cultural awareness, ecological conservation, and host societies contribution. So far these principle could lead to the main aspects of ecotourism which are cultural, social, economic and ecological. Tao, 2010 has criticized the previous ecotourism aspects stating that a lot of effort has done towards the preservation of natural areas, nerveless more attention need to be focused to disadvantages of development against damaging vegetation and disturbing the wildlife. Local participation could be a reasonable solution towards enhancing eco-development and ecotourism aspects.

### **Ecotourism International Dimensions and Guide lines:**

The international ecotourism society offered four main dimensions for developing ecotourism on community based cooperation and thus proposed twelve guide lines to verify theses dimensions (Lai & Nepal, 2006). The proposed dimensions are as follows:

- 1- Natural Resource conservation dimension argued the following, Contribution of ecotourism development to the natural ecosystems conservation, encouraging of local host communities to be a part of ecotourism development, &providing the educational required programs to local communities to raise their awareness of their natural heritage.
- 2- Cultural heritage preservation dimension discussed the following, Economic benefits from ecotourism development should balance rather than crush or replace the

traditional community practices, Providing the educational required programs to local communities to raise their awareness of their cultural heritage.

- 3- Sustainable development for community dimension stated the following, Negative environmental and socio-cultural impacts that results from ecotourism development should be minimized by operating such development in a responsible way, & Long term socio-cultural, economic, and environmental plan should be implemented to maximize the benefits to the host communities as well as the protected natural areas.
- 4- Participatory planning for ecotourism management dimension listed the following, Promotions to attract local resident participations, Tourists, local residents, government, protected area managers, tour operators, scientists, and NGOs should interact together with ecotourism developers before and during development process, & Ecotourism progression should maximize participation of local community.

The twelve guidelines for community-based ecotourism enterprises are then grouped into four different stages presented as follows (Liu et al., 2014). The first stage consider either ecotourism is a proper option or not. The second stage plan ecotourism with stakeholders and communities. The third stage develop sustainable ecotourism community based projects. The final stage strength reward benefits to both the environment and community.

Table 1. Shows the ecotourism guidelines.  
Source: Developed after Liu et al., 2014

Main Stages	Guide lines	Description
Consider either ecotourism is a proper option or not.	1. The gain received from conservation potential.	The positive impact of ecotourism on the relationship between conservation and local communities appeared through providing sustainable form of living for local communities.
	2. Examination the requirements for ecotourism	The fundamental prerequisites of ecotourism suitability should be checked before trailing community-based of the target area. Some prerequisites relate to the condition in the local area, others to situations at a national level.
	3- Adopting a unified approach.	Ecotourism could be more successful if it is integrated horizontally with the community activities and vertically with the national policies..
Plan ecotourism with stakeholders and communities.	4- Finding the superlative system to encompass the community	Concrete arrangements are required to allow the community to manage, benefit, and influence from ecotourism practice, and development. Legislation should be established to ensure a clear transparent relationship between community and ecotourism.
	5- Agreed strategy to work under its umbrella	National vision and strategy social, environmental and economic aims for ecotourism to regulate the relationship with the stakeholders and the community. Main benefit from working under national strategy is providing the community with knowledge and tools essential for decision making.
	6- Integrity of environment and culture.	Developed and planned tourism should be suitable for the area's cultural heritage and natural resources and reliable with the community's expectations and wishes, with acceptable change from the community to the tourism activities and development.
Develop sustainable ecotourism community based projects.	7- Effective marketing promotion for Eco tourism	Projects of Eco tourism should be based on expectations of consumers and market demand. As the main reason for the failure of community based ecotourism projects is the insufficient number of visitors.
	8- Quality of products should come first.	The second common reason for the failure of community based ecotourism projects is the quality of products offered to the visitors that should be executed through a subjective business plan.
Strength reward benefits to both the environment and community	9- Managing different impacts.	Clear Specified steps should be applied to maximize the benefit of ecotourism, and minimize the environmental impact.
	10- Technical support should be provided.	Continuing access to support and advice in the environmental management, development, marketing of good quality ecotourism products, handling visitors, hospitality skills, financial control and basic language training are required.
	11- Getting the support of tour operator and visitors	Ecotourism practices should raise the awareness of community issues and conservation among tour operators and visitors and comprise the way for enlisting this support.
	12- Observing performance to ensure continuity	Ecotourism projects should be planed and managed for long-term success and viability.

## Methodology:

This research adopted a logical unified multidiscipline methodology (LUMM) through investigating the evolution of ecotourism, its participants, key considerations for ecotourism

development at the community level, the NGOs role in promoting ecotourism, the industry demands for ecotourism, and finally the international guidelines. The research encompasses a set of organized categories of considerable amounts of qualitative data. Egypt strategies and policies was chosen as an example to for this study methodology application, which aims to explore the prerequisites for an ecotourism management plan and how it contributes to the community based developments. Accordingly, the results present a developed integrated framework to involve the community in managing and developing ecotourism. Consequently the contributed framework is considered a pilot one that firstly combines the international guidelines and the concurrent Egyptian guidelines taking into consideration the obstacles, to be overcome the threats, & strength the opportunities in the new proposed framework. It also target coping with the Egyptian protected natural areas and grantee running ecotourism development in a sustainable way that ensure resources conservation for the new generations, and community participation.

### **Case Study Egypt Status:**

A lot of obstacles stands as barrier to enhance ecotourism in Egypt. These obstacles are mainly limited in the following facts; started by the development procedure that are implemented separately without any integrated planning strategy between the different governmental organizations (Hassan & Denman, 2006). Followed by the governmental follow up for the bearing capacity of existing projects, it is a weak policy where the tourists visiting any of these projects are too much if compared to the environment adaptation capacity and considered as one of the main reasons that lead to environmental degradation (El Baroudy, 2016). Then the economic guidelines that control these types of projects are signified in the unfairness distribution for benefits, as the great revenue share goes to investors and operators with minimum share for hosting country (El-Barmelgy, 2005). Finally due to the political disturbance in Egypt since 2011, the project of Sharm el-Sheikh "Green Initiative" was suspended (Cattane, 2011). The aim of this project was to allow the city to adopt the sustainable standards of Egypt vision 2030 through enhancing the water supply, managing wastes, protecting biodiversity, and controlling harmful emissions (Cattane, 2011).

Egypt 2030 vision gives a high concern for developing ecotourism. The specialists did their best to propose a new guidelines that support the environment and stop its degradation ("Egypt's vision 2030," 2015). Proper implementation and zoning regulations strategies were proposed to encourage ecotourism sustainable development through five stages, which should be applied to identify the zoning of land use, and assess its degree of sensitivity (I. Shaalan, 2013). The first stage stated that collecting all the existing condition data should be imported in appropriate database in GIS. The second stage describes the criteria of dividing the target area into subzones through combining all the target layers. The third stage classified the subzones into areas grounded on their sensitivity to the impact of tourism projects. The fourth stage developed a land use zoning scenario based on different levels of subzones environmental sensitivity. The last stage established regulations for managing and conserving the land use subzones ("Egypt's vision 2030," 2015).

The result that concluded from the previous proposed guidelines divided the target land in five areas: "core zone for protective areas", "Buffer zone for wilderness restricted areas", "transition zone for ecotourism areas", "low development intensity zone for coastal resorts areas" and "moderate development intensity zone" as shown in the following figure ("Egypt's vision 2030," 2015). This mean that Egypt vision 2030 will lead to great change for Tourism Development Authority regulations as for example in the transition zone the

maximum density for resort rooms should be changed from 20 rooms per acres to 2 rooms per acres with maximum height that should not exceed three floors.

Beside the previous mentioned zoning regulations strategies the specialists proposed a set of guidelines to define the ecotourism destination characteristics as follows, Natural landscape preserved within natural habitats, Lands with abundant natural areas, less dominate built up construction, and low density of human development, Scientific studies to proof that tourism development will not cause harm for the surrounding natural systems like costal area, wildlife areas, wetlands, and waterways, Booming of well-motivated hotels, lodges, business, and restaurants that afford sincere hospitality with friendly staff, Thriving for small enterprises, including hand crafts and oriental food stands community business, Designing the outdoor recreation zone to encourage practicing activities through enjoying the interplay with nature, Holding local cultural festivals to engage the participating of the local communities, Public clean showers and toilets as a basic hygienic facility for tourists.

### **Results and discussion:**

Referring to (Drumm & Moore, 2005) Ecotourism became one of the most important economic activity all over the world that is responsible for developing natural areas. It gives the tourists the opportunity to experience other local culture and learn about biodiversity conservation, besides creating income, job opportunities and economic benefits for the hosting communities. Sarhan, Abdelgalil, & Radwan, 2016 stated the importance of applying ecotourism planning strategy in hosting local communities through a concrete guiding principles to ensure biodiversity sustainable conservation. Xu et al., 2017 pinpoint the difference between the natural tourism and ecotourism, as the first one lack the mechanisms for evaluating the environmental impacts and fail to establish respect to the hosting local culture, but economically, nature tourism is thriving. On the other hand, Masud, Aldakhil, Nassani, & Azam, 2017 investigated the initiatives of nature tourism and reached a results that shows incomplete sustainable strategy for conservation.

The promotion of managing community based ecotourism should be subject to residents' endorsement. Ashok et al., 2017 discussed that successful management for natural conservation areas will not succeeded without the cooperation from local communities that should be an important partner in biodiversity decisions. However K. Amer & ElSayed, 2016 suggested that conservation programs should not only consider the environmental dimensions, but also economic and social situations of target hosting communities, as well as their attitudes, interests, and values that can be effectively a part in conservation and development plans. While Lai & Nepal, 2006 discussed the resemblance between community intention and attitude together towards ecotourism dimensions.

Nevertheless the researcher proposed a set of guiding principles to manage the community based ecotourism. These principles are; specialized types of marketing that attract travellers who are interested mainly in visiting natural conservation areas, Managing skills to handle visitors in conservation natural areas, Guiding services managed by local residents, should focus on sustainable development concerns and natural history, and finally Assigning fees from tourism for funding both sustainable development of local communities and conservation of ands.

Natural protected areas may be owned to community, state, private, or any combination of them. Great awareness for the management mechanisms should be applied by the developers to ensure sustaining the activity. Egypt as a developing country, lack



concrete guiding principles to ensure site conservation sustainability, local community participation which in return may pose threat to natural areas. For ecotourism to accomplish its potential and complete sustainable profits, natural areas should implement a strategic planning framework to manage and guide the activity. The research focuses mainly on providing a combination set of criteria for both the international and concurrent guiding principles to managers and planners at ecotourism organizations. However, the proposed framework may also be helpful to community, economists, and protected area specialists, as well to other participants in ecotourism including hotel developers, tour operators who are trying to understand the conservation consequences of proposed activities. Finally this framework may also be of use to private & public investors. The proposed framework will be illustrated on five phases. Phase one will define the ecotourism participants and their role in developing such sustainable activity. Phase two will illustrate the ecotourism opportunities and threats. Phase three illustrates the role of hosting community in developing the sustainable ecotourism. Phase four discusses the role of NGOs in developing ecotourism. Phase five investigates conflicts between conservation specialists and tourism industry. And finally phase six will present (LUMM) framework.

**Phase one:** Ecotourism participants play essential roles in developing such an activity.

**Starting by local communities:** they are the residents who live near or in natural preserved areas and not homogeneous group. Local community plays an important role in developing ecotourism because the natural areas are considered their homelands that need participatory planning and management, besides local community are the key players in preserving natural resources, and their relationship with nature will determine the degree of success with conservation strategy.

**Followed by Tourism industry:** It is huge sector that involves a great variety of people including tour operator and travel agents. Their role in developing ecotourism is very important as they have a great awareness of what tourists want and how they act. They also play a main role in promoting ecotourism.

**After that Government agencies:** Many departments in government participate in ecotourism planning, management, and development. These departments may include wildlife and protected areas, natural resources, tourism, community development, finances, transportation, and education. Their main role is establishing and promoting policies for natural protected areas.

**Next NGOs:** They propose means of communication with large numbers of interested entities. NGOs serve as a bridge to gather together all ecotourism elements through site administrators, program managers, advisors, trainers, business partners, and ecotourism companies or communities. Another group of NGOs are called for-profit tourism associations including hoteliers, airlines, and private tour operators. The last group includes the private non-profit ones, which mainly focus on biodiversity conservation.

**Finally supporting player:** They are divided into three subgroups which are funds, tourists, and education sectors.

**Funds:** Different institutions and groups can fund the ecotourism development through grants or loans. These institutions include investment corporations, multilateral and bilateral donor agencies such as private investors and World Bank. These institutions shouldn't participate in planning or taking decisions for ecotourism destinations and development.

**Tourists:** they are the main players in ecotourism system and they are also the main target for developers to reach their satisfaction and happiness.

Education sector: they are group that are responsible to raise questions to be sure that ecotourism reached its goals.

### **Phase two: Ecotourism opportunities and threats.**

Opportunities and threats, and subsequently benefits and overheads, will differ from state to another, from individual to another and from group to another. One group benefits may be costs to another. Defining which opportunities to follow and which threats to decline is a decision that can be made by including all stakeholders. Classifying the importance of each advantage is part of the bargaining involved in the planning ecotourism process.

#### **Ecotourism opportunities:**

**Revenue Generation:** Getting money into natural protected areas is a main concern of conservationists. Funds available for natural protected areas have been decreasing, and many natural protected areas will not last without new revenue sources. Tourism propose opportunities to get revenue in different ways, such as user fees, entrance fees, donations, and private sector concessions. New funds let the managers of the natural protected area to better handle tourists and to stand against threats.

**Employment Establishment:** The biggest gain cited from tourism are new jobs opportunities. Jobs may be researchers, guards, managers, or guides. In the surrounding community, residents may work as tour guides, taxi drivers, handicraft makers, and lodge owns, or they may be a part of tourism enterprises.

**Justification for Protected Areas:** Potential to attract visitors, or Visitors themselves are considered among the reasons that residents and government officials give support to natural protected areas. Preserving natural protected areas needs long term vision; which is a challenge for government officials.

**Environmental Education:** Tourists are always eager to know about the local habitat, as they want to learn about plants, animal behaviour, and challenges of preserving theses resources.

**Biodiversity Maintenance:** The maintenance is one of the main factors that ensure sustainability for the natural protected areas.

**Visitor Appreciation/ Awareness:** Appreciation is considered the less tangible benefits than the other listed elements.

**Cultural Exchange:** is one of the main important advantage that both hosting community and tourists can get benefit from.

#### **Ecotourism Threats:**

**Environmental Degradation:** this is one of the main important threats that is associated with tourists' visiting to natural areas. As many of the tourists destroy the resources they come to see. Degradation may happen in varying degrees and in many ways.

**Economic Distortions:** Ecotourism is like any activity that can be unstable source of income. Many external factors may affect the tourist demand like political conflict or rumors, natural disasters, and fluctuations in hosting country currency.

**Increased Control by Outsiders:** Political agreements and strategies may cause negative impacts on ecotourism development.

**Industry Instability:** This is one of the main threats that cause degradation to ecotourism.

**Diminished Visitor experience:** If the visitors did not form an identical cognitive map to the ecotourism destination, so this may be a cause to environment degradation.

**Cultural Distortions:** Conserving the culture of the hosting community is a main factor for flourishing ecotourism, and vice versa.

### **Phase three: The role of community in developing ecotourism.**

Heterogeneous group of people living in the same area and enjoys surrounding natural resources are called community. Diverse and multiple elements important for guaranteeing that communities achieve their role in developing ecotourism. Starting by planning level, the national plans should include community role as a main factor in the development, so the community participation will not be a volunteer action but an obligatory rewarded one, followed by education and training for community, as they should be aware by the best ways for dealing with natural protected areas to ensure sustaining for a long time. Ending with high economic rewards from developing ecotourism to community.

Community participation in developing ecotourism has a positive potentials on both community and tourism. The following table will illustrate both the positive impacts that results from community participation and the negative impacts that result from community observation.

Table2. Shows Positive & Negative impacts for community participation

Source: Author

With Community Participation		Without Community Participation	
For Communities	For natural areas	For Communities	For natural areas
Income Suitability	Reduce threats	Erosion of natural areas	Increase threats
Services Improvement	Steady economic development	Economic inequity	Unstable economic development.
Cultural empowerment	Natural areas conservation	Cultural erosion	Overuse of natural resources
<b>POSITIVE</b>		<b>NEGATIVE</b>	

#### Phase four: The role of NGOs in developing ecotourism.

Since there is a direct relation between ecotourism and nature conservation, so NGOs conservation agencies plays an important role in developing this activity. Their role can be summarized as follows; NGOs acts as a catalyst agent that facilitate the relations and between different ecotourism partners.

- 1- -NGOs role not only depend on achieving conservation impact, but also on providing services to the community enterprises and private companies.
- 2- NGOs plays the role of trainers and expertise in ecotourism field to support other institutions with the required information.
- 3- NGOs together with natural area administration implement the features of ecotourism program.
- 4- Besides managing their own private protected natural areas, NGOs are asked to manage the government administrated protected natural areas.

#### Phase five: Ecotourism Industry.

In all ecotourism participants, the tourism industry is the least appreciated by preservationists, as they do not like to deal with profit interested enterprises. Nevertheless, tourism industry enterprises plays an essential role in achieving ecotourism goals. They can become partners and allies with protected area managers, NGOs, and communities. Examples of the activities that tourism industry encourage are encouraging tourists to reuse towels, recycling bottles and cans in order to save water. The tourism industry chain includes the following sectors travel agent, operators (outbound), operators (inbound), and local services provider.

- a. **Travel Agent:** Retail outlets or shops that propose international and domestic travel services to tourists who can communicate in for direct disscusion with the sales person in their neighbourhoods or towns.

- b. Operators (outbound):** They produce the annual brochures with fixed departures for each tour program, and they have a trusty cliente purchasing trips steady basis.
- c. Operators (inbound):** Located in the host county, they afford services' packages from depature to country arrival.
- d. Local Services Provider:** Besides the protected natural areas, there may be transport providers, lodge and hotel owners, and community based ecotourism enterprises. The former mentioned items are in the chain of tourism industry.

**Phase Six: LUMM Integrated Framework.** Finally after reaching the final phase, all the previous phases together with the intenational guidelies and principles for ecotourism have been integarted to form the LUMM following framework.

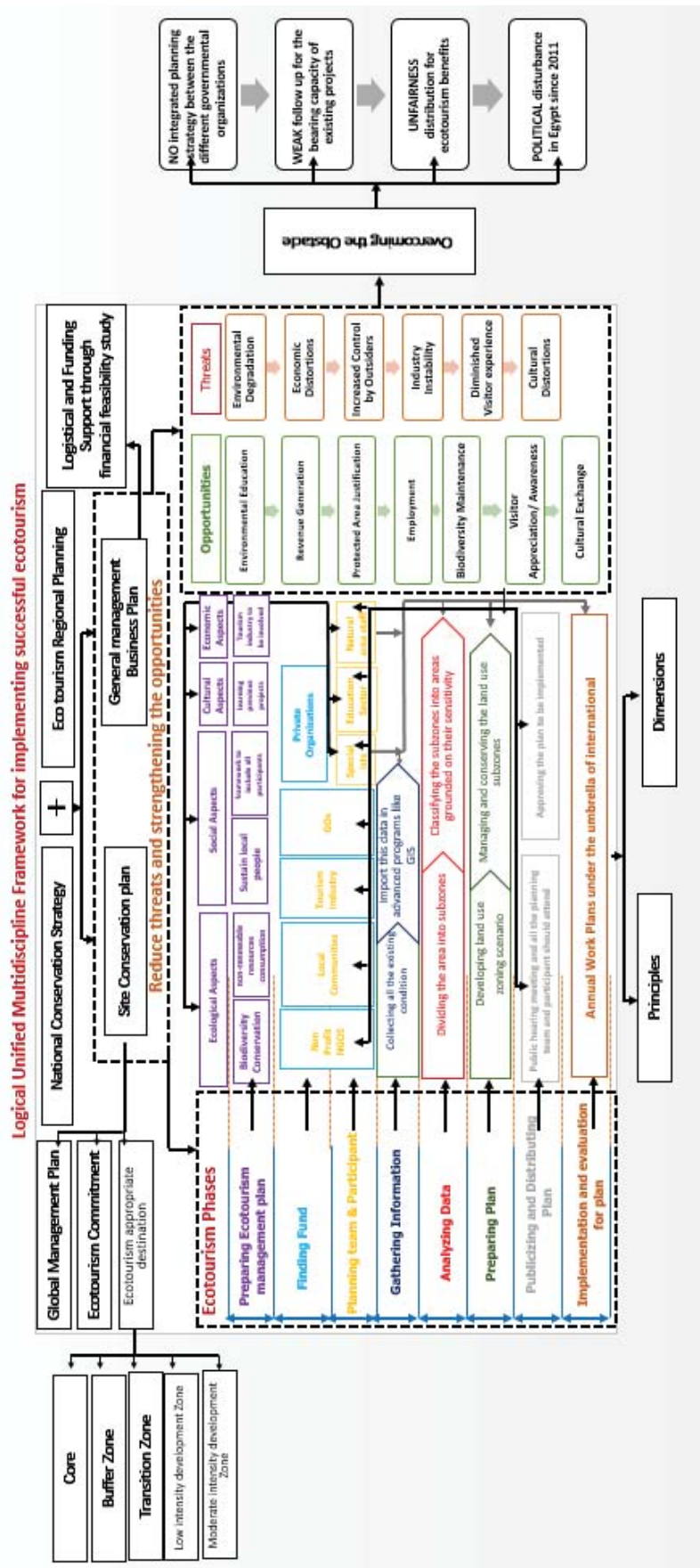


Figure 5 shows LUMM integrated framework  
Source: Author



## Refernces:

- Arsić, S., Nikolić, D., & Živković, Ž. (2017). Hybrid SWOT - ANP - FANP model for prioritization strategies of sustainable development of ecotourism in National Park Djerdap, Serbia. *Forest Policy and Economics*, 80, 11–26. <http://doi.org/10.1016/j.forpol.2017.02.003>
- Ashok, S., Tewari, H. R., Behera, M. D., & Majumdar, A. (2017). Development of ecotourism sustainability assessment framework employing Delphi, C&I and participatory methods: A case study of KBR, West Sikkim, India. *Tourism Management Perspectives*, 21, 24–41. <http://doi.org/10.1016/j.tmp.2016.10.005>
- Avraham, E. (2016). Journal of Hospitality and Tourism Management Destination marketing and image repair during tourism crises : The case of Egypt, 28, 41–48.
- Bertellotti, M., D’Amico, V., & Cejuela, E. (2013). TOURIST ACTIVITIES FOCUSING ON ANTARCTIC PENGUINS. *Annals of Tourism Research*, 42, 428–431. <http://doi.org/10.1016/j.annals.2013.02.017>
- Cicin-Sain, B., & Belfiore, S. (2005). Linking marine protected areas to integrated coastal and ocean management: A review of theory and practice. *Ocean & Coastal Management*, 48(11), 847–868. <http://doi.org/10.1016/j.ocecoaman.2006.01.001>
- Denman, R. (2001). *Guidelines for community-based ecotourism development*. (R. Denman, Ed.)Report. UK: Rufford Foundation. [http://doi.org/10.1002/1522-1970\(200101/02\)3:1<72::AID-JTR276>3.0.CO;2-4](http://doi.org/10.1002/1522-1970(200101/02)3:1<72::AID-JTR276>3.0.CO;2-4)
- Drumm, A., & Moore, A. (2005). An Introduction to Ecotourism Planning. *Nature*, 1, 85. Retrieved from <http://dukespace.lib.duke.edu:8080/dspace/handle/10161/3632>
- Egypt’s vision 2030. (2015). Sharm El Sheikh, Egypt: Egypt economic development conference.
- Egypt Tourism. (2000). Egyptian Tourism Authority. Retrieved July 20, 2005, from <http://www.egypt.travel/>
- El Baroudy, A. A. (2016). Mapping and evaluating land suitability using a GIS-based model. *CATENA*, 140, 96–104. <http://doi.org/10.1016/j.catena.2015.12.010>
- El-Barmelgy, H. M. (2005). To “Eco-wise” or to “Sustain-wise””, Development and Tourism in Coastal Areas. In *INTA 2005 International Conference at Sharm El-Sheikh, Egypt* (pp. 1–17).
- El-Sayed, M. A., Mahmoud, A. H. A., & El-Barmelgy, I. M. (2015). *Land Suitability Analysis for Urban Green Areas Using New Methods and Techniques*. Cairo, Egypt: LAP LAMBERT Academic Publishing (August 25, 2015). Retrieved from [https://www.amazon.com/Suitability-Analysis-Urban-Green-Areas/dp/3659410721/ref=sr\\_1\\_1?s=books&ie=UTF8&qid=1492514685&sr=1&keywords=land+suitability+analysis+for+urban+green+areas](https://www.amazon.com/Suitability-Analysis-Urban-Green-Areas/dp/3659410721/ref=sr_1_1?s=books&ie=UTF8&qid=1492514685&sr=1&keywords=land+suitability+analysis+for+urban+green+areas)
- Environment, M. of. (2015). Egypt State of the Environment Report. Retrieved June 1, 2017, from <http://www.eeaa.gov.eg/en-us/home.aspx>
- Hassan, A., & Denman, R. (2006). Red Sea Sustainable Tourism Initiative. In *Making Tourism More Sustainable, Part 2; Case Studies*. (pp. 144–148). Cairo, Egypt. Retrieved from <https://www.unpei.org/sites/default/files/PDF/policyinterventions-programmedev/Making-tourism-more-sustainableENpart2.pdf>
- Hong, L., & Yan, J. (2011). Study on Construction Ecotourism City Based on Theory of Recycling Economy. *Energy Procedia*, 5, 1932–1936. <http://doi.org/10.1016/j.egypro.2011.03.333>
- K. Amer, S., & ElSayed, M. A. (2016). Practicing new methods and techniques to enhance site selection for ecotourism lodges. In *Egypt 2016. Second International conference on the sustanaibility and future “Chance – Change – Challenge”* (pp. 202–207). Cairo, Egypt: Elain Publishing House.

- Lai, P.-H., & Nepal, S. K. (2006). Local perspectives of ecotourism development in Tawushan Nature Reserve, Taiwan. *Tourism Management*, 27(6), 1117–1129. <http://doi.org/10.1016/j.tourman.2005.11.010>
- Liu, J., Qu, H., Huang, D., Chen, G., Yue, X., Zhao, X., & Liang, Z. (2014). The role of social capital in encouraging residents' pro-environmental behaviors in community-based ecotourism. *Tourism Management*, 41, 190–201. <http://doi.org/10.1016/j.tourman.2013.08.016>
- Masud, M. M., Aldakhil, A. M., Nassani, A. A., & Azam, M. N. (2017). Community-based ecotourism management for sustainable development of marine protected areas in Malaysia. *Ocean & Coastal Management*, 136, 104–112. <http://doi.org/10.1016/j.ocecoaman.2016.11.023>
- Organization, W. tourism. (2017). *Practical Guidelines for Integrated Quality Management in Tourism Destinations*. Spain. Retrieved from <http://www.e-unwto.org/doi/book/10.18111/9789284417988>
- Sanò, M., Richards, R., & Medina, R. (2014). A participatory approach for system conceptualization and analysis applied to coastal management in Egypt. *Environmental Modelling & Software*, 54, 142–152. <http://doi.org/10.1016/j.envsoft.2013.12.009>
- Sarhan, A., Abdelgalil, R., & Radwan, Y. (2016). Ecotourism principles as a framework for culturally responsive community development, 201(St), 15–25. <http://doi.org/10.2495/ST160021>
- Shaalán, I. (2013). *Sustainable urban transformation in small cities in Egypt: a UN-habitat perspective*. *Journal of Cleaner Production* (Vol. 50). Retrieved from <http://www.sciencedirect.com/science/article/pii/S0959652612006142>
- Shaalán, I. M. (2005). Sustainable tourism development in the Red Sea of Egypt threats and opportunities. *Journal of Cleaner Production*, 13(2), 83–87. <http://doi.org/10.1016/j.jclepro.2003.12.012>
- Shiaty, R. El, Taalab, M., & Osama, I. (2016). Evaluating the Performance of the Outdoor Spaces in Healing Eco-Tourism. *Procedia Environmental Sciences*, 34, 461–473. <http://doi.org/10.1016/j.proenv.2016.04.041>
- Tao, T. C. H. (2010). Ecotourism and Environmental Sustainability: Principles and Practice. *Annals of Tourism Research*, 37(4), 1198–1200. <http://doi.org/10.1016/j.annals.2010.07.005>
- Tell el-Borg. (2014). *Excavations in North Sinai*. (J. K. Hoffmeier, Ed.). Eisenbrauns. Retrieved from <http://ebookcentral.proquest.com/lib/bue-ebooks/detail.action?docID=3155712>
- Travel, Communities & sustainable, U. C. (2013). The International Ecotourism Society. Retrieved July 20, 2017, from <http://www.ecotourism.org/>
- UNWTO. (2017). World Tourism Organization. Retrieved May 1, 2017, from <http://www2.unwto.org/en>
- Wearing, S. (2011). Ecotourism and Environmental Sustainability: Principles and Practices. *Tourism Management*, 32(1), 196–197. <http://doi.org/10.1016/j.tourman.2010.01.004>
- Wood, M. E. (2002). *Ecotourism : PRINCIPLES, PRACTICES & POLICIES FOR SUSTAINABILITY*. (T. I. E. S. United Nations Environment Programme, Ed.) *The International Ecotourism Society*. United Nations Publication. <http://doi.org/10.1079/9781845934002.0000>
- Xu, S., Mingzhu, L., Bu, N., & Pan, S. (2017). Regulatory frameworks for ecotourism: An application of Total Relationship Flow Management Theorems. *Tourism Management*, 61, 321–330. <http://doi.org/10.1016/j.tourman.2017.02.012>

## **“Leaping city”**

### **Addressing Sustainable development in small scale cities in Egypt**

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**Abstract:** Egyptian cities face major challenges in coping with emerging economic, social and environmental crises that are looming, where creating jobs for the young is one major challenge, providing fresh water, energy, and food are as well becoming both urgent and critical for the decent survival for people in Egypt.

A small-scale city, with around fifty thousand residents such as El Qusier, is where one can detect those challenges closely. The eminent climate change is making the state of those challenges even worse. As Egypt is one of the highest five states vulnerable to climate change despite its very low contribution to GHG emissions. The slow response by the government, which is still shying away from addressing this situation properly, is coupled with evident economic and political uncertainty. No potentially successful planning proposal can contribute positively without addressing such context.

This paper is investigating the potential to approach local challenges in the city of El-Qusier as developmental opportunities, using mainly the local available resources. This approach aims at conceptually experimenting with the idea of creating small-scale interventions that can instigate a network of sustainable local environment. The modest initials of these networks are thought of to eventually develop into more elaborate environments using the help of more advanced local technologies and education. Five different types of city identified potential environments for initial developments are selected and specific proposals are developed for each as to show whether the proposed idea can work or not.

**Keywords:** Sustainable urbanism, red sea cities, microsystems, climate change

### **Introduction**

Egypt faces many challenges in respect to the type of development it should undertake; this led especially during the last four decades to major problems (Sims, 2014). In addressing Egyptian urban environment, our concern for sustainable development led us to search for poorly used spaces of social housing and public schools and others, they are, by default network of institutions, of communities and of users.

Like many Egyptian cities, El Qusier faces major challenges. The challenge of creating jobs mainly for the young is one major challenge with many complex consequences (UN, 2010). Main resources that are necessary for survival such as water, energy, and food are in dire situation.

ElQuseir is one of the coastal Red sea cities in Egypt. It is located 600 km to the south of Cairo and 180 km from the nearest Nile riverbank. The city witnessed some major transformation from a fishing village to an “industrial city” to a more recent tourist destination. The post fossil city international competition organized by the urban future studio (Hajaer, 2016) was an opportunity to explore some ideas regarding the future

situation of ElQusier, which we believe can help develop a more developed strategy for other cities.

### **Climate change and sustainable development**

Globally, climate change is considered by many to be The Challenge for our future, a challenge that requires a totally new approach to life and economy (Klein, 2014). The Situation in the African continent is critical as the continent is one of least responsible yet is one of the most vulnerable to the potentially catastrophic consequences of Climate change (Toulmin, 2009). Despite the fact that Egypt contribution to GHG emission is very low, Yet Egypt is one of highest five states vulnerable to climate change (MoE, 2016). This calls for immediate actions and plans to prepare for a hard future. Yet reacting to the challenges that will be brought by climate change necessitates a totally different strategy to deal with the Egyptian built environment compared to what is already been done.

One major report that has been produced in 2015 is Egypt sustainable development strategy 2030. This report addresses the UN SDGs, which include measures to deal with climate change. This report can be as well an important tool to review the way by which urban development is addressed mainly in Egyptian cities. The GOPP reports produced in last of century shows a serious lack in addressing both climate change and sustainable development (GOPP, 1998). As the Paris COP21 accord shows clearly both are closely linked. GOPP strategic plan for Egypt 2052 predated the SDS Egypt 2030 this might have to do with some major contradiction or shortcomings one can find in Egypt 2052. For example, the 2052 plan does not highlight the MDGs that predated the SDGs. As for dealing with major recourses such as energy and water many problems can be pointed out. On the other hand, Egypt strategy 2030 takes UN SDG as a clear and major reference in terms of goals and time frame.

### **Political and economic context**

Recent economic indicators of Egypt show that the numerous challenges that underline the political eruption of 2011 where the slogan was Bread, Freedom and social justice are still existent (Gamal, 2016). The real question of development in Egypt now is how to address serious issues that need to be discussed publicly and critically such as sustainable development. Furthermore, the issue of how to publicly and critically address the eminent challenges that required transparency, access to information and availability of arena for public debate cannot be thought of given the political and economic context in hand. The situation that David Sims pointed to regarding the spread of informal housing and informality indicates clearly a condition that proves the absence of the government is more or less still there (Sims, 2010).

### **Local challenges as future opportunities**

The electricity cuts during 2012-2014 highlighted the energy crisis that Egypt faces. Many scholars went into investigating not only the current situation but also the likely scenarios of the future of electricity in Egypt (Bottoms, 2016). Public discussions on the Egyptian objection to the Ethiopian dam construction also shed clear light on what is known for some years now as the eminent water crisis (El Bedawy, 2014). Increasing population and decreasing agricultural land accompanied by soaring food prices every now and then points

as well to the increasing food crisis (Dixon, 2017). Those three major challenges that face Egypt will be outlined as they appear in ElQusier.

The city currently relies on conventional, non-local energy resources, which are not either secure or sustainable. 25MW assigned for Al-Quseir electricity comes from the 90 km to the north, Safaga. Based on the site visits and observations, it is safe to say that Al-Quseir is industrial, economical, and productively inactive. And this, in return, affects the energy profile of the entire city and the individuals living in it. Comparing the primary energy consumption per capita (CPC) in Al-Quseir to Egypt and other countries like Germany, China, etc., significant gaps clearly emerge. For example, in 2014 CPC in Germany was 37,216 MW.h/thousand people, China's was 19,190 MW.h/thousand people, India's was 4768 MW.h/thousand people, and while in Egypt was 11,049 MW.h/thousand people, the respective CPC of El-Quseir is estimated at 972 MW.h/thousand people<sup>1</sup>.

As for the water challenge; Historically El Qusier depended on water wells, now two main resources are supplying almost all the resident's needs; 1- fresh Nile water through a pipeline from Safaga that brings 1500 m3 per day, 2- Desalination plant with a formal capacity of 7500 m3 per day. The quality of desalination water is according to most people we talked to in the city are highly in doubt and cannot be used for drinking and other cooking uses<sup>2</sup>. The water distribution company pump water to residents (once a week through the public network), this makes the need for water storage facility at each house is a must. An annex building to hold water storage containers for each apartment was added to most late twenty century social housing. Water storage materials vary from concrete to steel to pvc adding serious concerns for water safety. The foreseeable Nile water shortage adds a real challenge to the water situation in the city in terms of citizens' health concerns and as well in terms of responding to needs arising from other activities such as tourism and other potential activities.

The main food market in El Qusier opens only every Thursday and Friday, which clearly indicate the size and demand for food in the city. Yet a number of retail vegetables, fruit and fish stores scattered around the city. Talking to the city residents and shop owners show that most of the fresh food comes from Cairo wholesale, a market which is more than 600 km away adding significant food mileage to it. Some also come from Qift, which is around 180 km away. Obviously, this affects the quality of food and adds to its prices in addition to contributing to environmental pollution. People in El Qusier used to live on fish as they were mainly fishermen, then with the development of the city as a port and settlement of a larger number of population other types of food were regularly imported from nearby locations such as Qift. The modern development of the city and introducing industrial activities into the city and settling of growing population helped make a significant change in people diet more permanent with a growing dependency on imported food. Facing the growing food crisis globally and nationwide in Egypt requires people to resort more to local resources and taking the need for a change in diet seriously. This might have as well health benefits not only economical ones. Fishing not only in the city but in much of the red sea will suffer from the impact of climate change. The expectations are that the fish catch will be reduced by around 50% per cent. This significant reduction will add to the fact that the red sea already has a relatively low catch.

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<sup>1</sup> Calculated by Sarah Salah based on site visits within the context of the Egyptian city class.

<sup>2</sup> Almost all people we met in the city complain of water quality.



### **Small-scale interventions or Microsystems as an approach to sustainable development**

Large scale urban interventions even in a normal and favourable political context would still have intrinsic difficulties and even problems (Elhady, 1997). On the other hand, small-scale interventions are based on the possibility of the local economy to be based mainly on the local resources and using simple skills and technologies. This would be the same premise of “blue economy” (Pauli, 20). The question becomes then on the extent to which small-scale urban interventions and hopefully innovations can enhance our localities in the near and medium future is a relevant one. The target of any development project should be to help local communities improve their environment and become productive entities positively contributing in aspects such as urban agriculture, renewable energies, and sustainable mobility. If it is possible to transform poorly used spaces within the city, in particular in social housing and public schools into productive spaces, then many benefits can be brought in. Hopefully then being transformed into more welcoming places of exchange of ideas. And it may be that the knowledge and ideas to be exchanged are the knowledge and ideas produced (and at risk of being lost) by the city and for the city in the settings of learning and doing. To explore the potential of this process further the proposed project will identify selected places to start with in ElQusier, looking at the potential for using this neighbourhood’s social housing spaces and schools as knowledge depositories and factories from which these catalysts emerge as interventions.

#### ***Productive social housing as a Microsystem:***

Social housing in ElQusier occupy considerable parts of the city. They follow a typology one can find everywhere in Egypt the 1980s and 90s. The concrete skeleton that is added next to some of them provide near shelter for water tanks for the residents is an added facility and a clear indication of the severity of the water crisis in the city. Large open and often underutilized spaces between buildings are unmistakable shared quality. Our proposal is to encourage the residents around each space to initiate an informal cooperative in order to make simple green houses to produce vegetables. The amount of produce is estimated to be more than what they need in their daily life hence allowing them to sell the excess. Roof top solar stills will provide desalinated & heated water for the residents, as well as irrigation possibility to maintain productive greenhouse gardens. The proposed efficient solar stills are based on research conducted in KSA (Ayoub, etal, 2015). Within the green houses, a soilless system that already been tried in a number of desert places in Egypt will be used as it is also used as much as less water as 90% from the usual needs see fig.2.

Eventually, a more efficient use of water will be needed and a grey water system that would also allow for the more efficient use of municipal water will be installed using simple ground sand filters. A small or nearby packaging kiosk will be added eventually. Online ordering system can also help keep fresh deliveries. Organic waste from the cultivation process can be transformed into organic soil essential for the small nurseries needed for the green houses. Other organic waste from the surrounding residents can also keep this process working. As the production process stables in few years, more development can be thought of in order to increase productivity and hence the return of such a small project as seen in fig. 3.

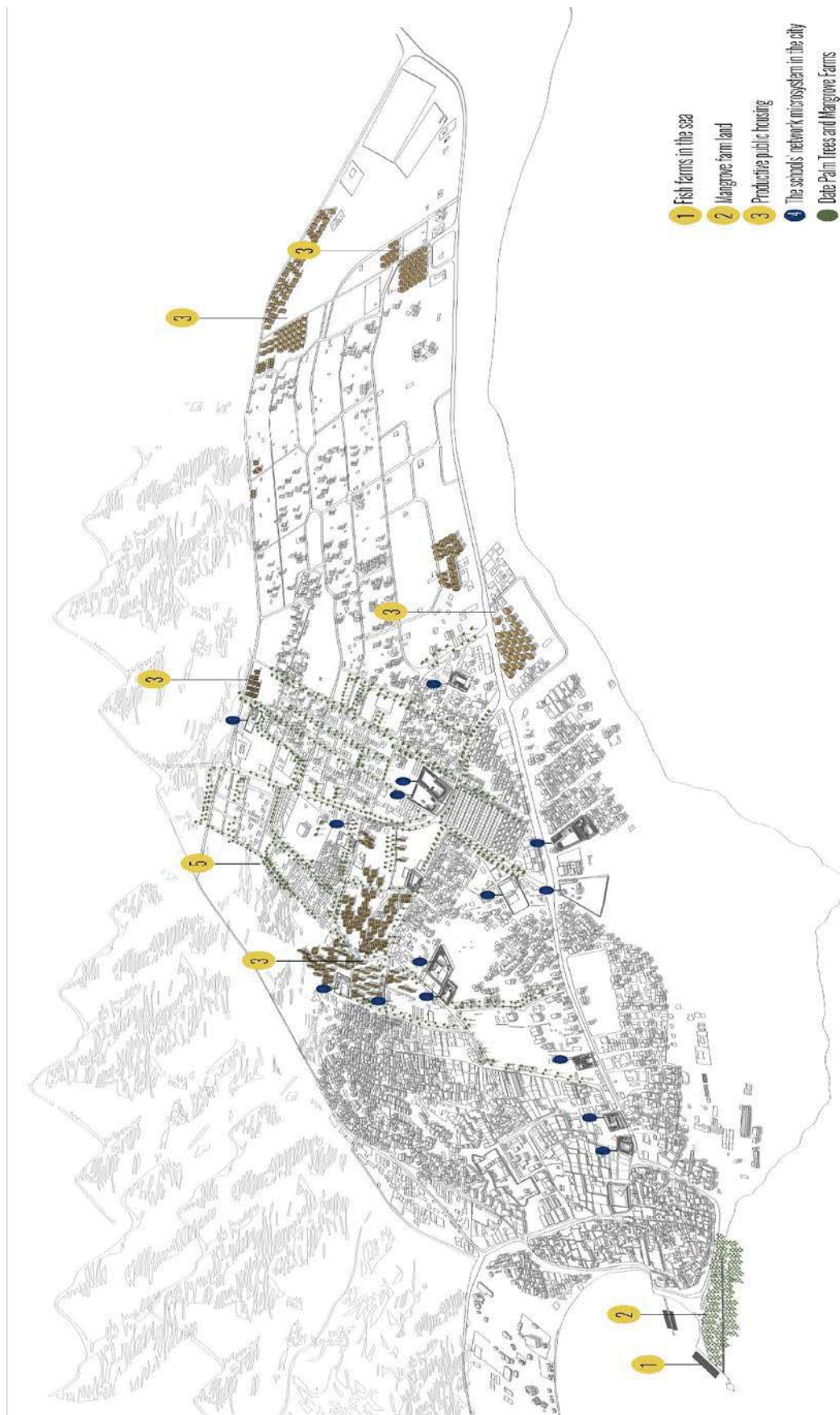


Figure 1. A 3D image of the city showing the locations of the different small-scale interventions



Figure 2 A 3D image showing how one of the public housing spaces would look like.

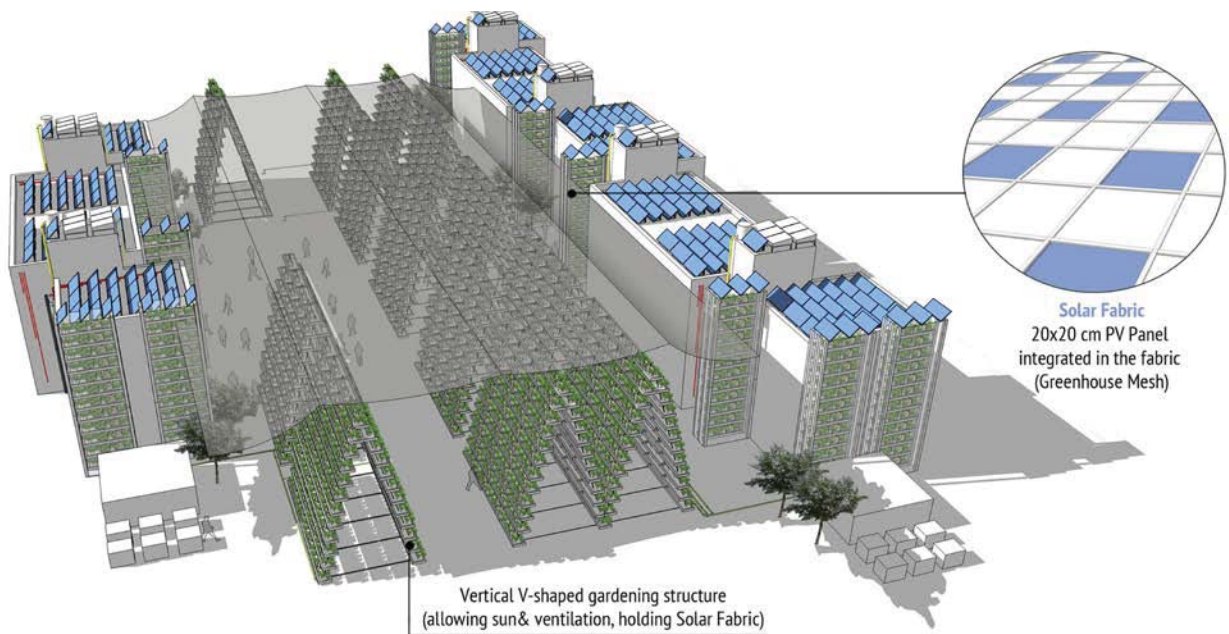


Figure 3 A 3D image showing how the second phase of the public housing spaces would look like.

### ***Productive schools as Microsystems:***

Our proposal is to insert greenhouses within the schoolyards and if possible on rooftops. Solar heaters and water stills on rooftops will help produce enough fresh water to irrigate plants in the green houses. The green houses and solar stills should also be used as teaching materials and ways to bring environmental issues in an interesting way into the school curricula. The students will be required to render a certain amount of work weekly to be



enrolled in the school. The teachers will be given a significant portion of the production as incentives for their work done. This particular aspect draws on an experiment done on planting simple green planters on top of school by an NGO back in 2013 northern Cairo.



Figure 4. A 3D image showing how one of the schools in the city might look like

#### ***Productive streets as Microsystems:***

Considerable areas of the city are occupied by relatively very wide streets which defy the climatic need for shade in a mostly desert context. In addition, they constitute a substantial waste of land. Our proposal included narrowing the asphalt for cars that would make it possible to plant date palms, which will provide edible fruits while consuming considerably little water. Also providing shade that will help make use of the sidewalks for pedestrians & bikers. The streets will be planted by residents and shop owners living on the street with each having a share of at least one palm tree & will be able to share its return (or its value). The buildings overlooking the streets will be installed with solar stills on the rooftops to produce fresh water for irrigation and other uses as well, see fig. 5.



Figure 5. A 3D image showing the public street spaces and how they would look like

#### ***Integrated plants & fish farms in the sea as a Microsystems:***

The yield of the Red Sea is relatively low, a situation that will get worse over the coming years as a result of climate change. Our proposal is to initiate an informal cooperative of the

existing fishermen & those willing to join the profession. This arrangement will not only help grow more fish but vegetables as well. The floating green houses will use solar-heated enhanced solar stills to accumulate enough fresh water to irrigate the plants in a soil-less environment. Eventually, these floating greenhouses can integrate PV modules on top & have a more efficient system of producing fresh water and safely re-using the left salty water.



Figure 6. A 3D image of the proposed fish farms at and near the existing port

### ***Mangrove farms as Microsystems:***

Mangroves grow on salty seawater. They are amazing creatures that can filter salt from seawater to survive & grow. They can be found to the north and south of the ElQusier. Mangroves usually grow in the shallow water, which is one of the characteristics of beaches in El Qusier, especially from the port northward. They can provide food for goats & other livestock that are usually domesticated by people living in the desert environment as a valuable source of animal protein. They can also provide a good place for oyster farming like the ones used in South Asia.

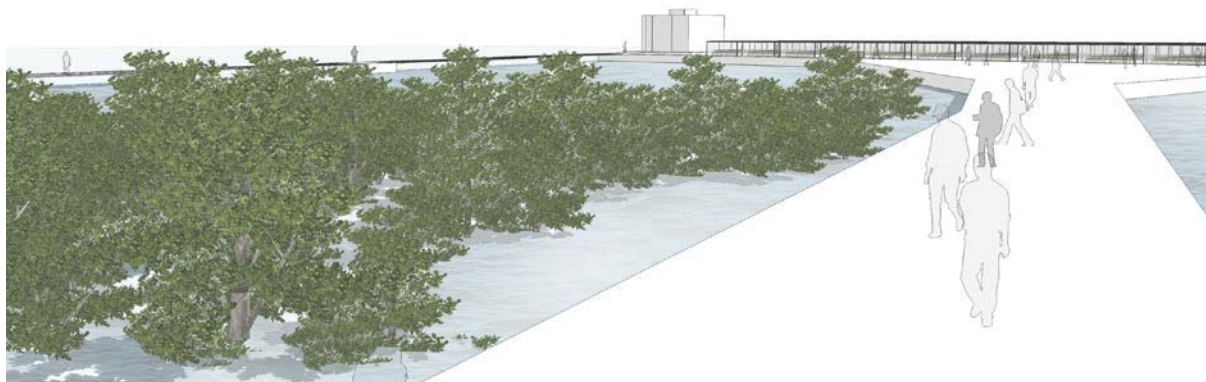


Figure 7. A 3D image showing the proposal for the mangrove farms along the sea shore

### **Conclusion**

Our understanding of sustainable development is people centred as well as being grounded on using local resources. Whether these resources are money, available natural resources such as seawater, desert plants, or local human capacities and skills. For us local technologies and know how is instrumental as they kick start a great potential for development and potential local innovations. This could eventually lead to creating opportunities resulting from accumulated experiences, skills, improving education and health services. Based on our proposals shown previously, we think that the spread of small



scale interventions and microsystems will allow a considerable percentage of the city citizens to be active participants in the local economy. Then a new economic situation will take place, which will impact the local political scene. Representation, citizenship, and politics will change. There might be a need for a diverse economic base and scales. That is what I tried to do with my students at the sustainable development class. Another integrated action to the ones proposed in introducing sustainable tourism to historical parts of the city in a way that will benefit the citizens and help preserve the invaluable historical fabric. Whether the previous proposals are utopian in nature or potentially real. As the informal experience during the previous decades in Egypt shows, creating parallel systems to the government is a real possibility. While it is not perfect but it is much better than being in a situation where future and security of the citizens are being compromised through extensive dependency on foreign loans and accumulating massive amounts of debt that is not sustainable even in the medium range.

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## References

- Ayoub, G. et al, "A Solar Still desalination system with enhanced productivity", 2015, Journal of desalination and water treatment, Volume 53, issue 12
- Bottoms, I., "80 Gigawatt of Chang; Egypt's future electricity pathways", 2016, ECESR and HBS North Africa, Tunis
- CAPMAS (Central Agency for and Statistics), 2015, 2017
- Dixon, M., 2017, "Food and crisis in Egypt; Corporate food and class inequalities", *Thimar* no. 184 (research collective on agriculture, environment, and labour in the Arab world)
- El Bedawy, R., "Water Resources Management: Alarming Crisis for Egypt", 2014, Journal of Management and Sustainability; Vol. 4, No. 3; 2014 ISSN 1925-4725 E-ISSN 1925-4733 Published by Canadian Centre of Science and Education
- Elhady, N., 1997, *Ethics of urban form production*, Ph.D. dissertation, Cairo University
- Gamal, W. ed., 2016, *Egyptian Economy in the twenty first century*, Al Maraya, Cairo
- GOPP (General Organization for Physical Planning), 1998, Master plan studies of ElQusier, Cairo, in Arabic
- Khalil, H., 2016, *Informal Economy as an alternative economy for Egyptians*, in Gamal, W. ed., 2016, *Egyptian Economy in the twenty first century*, Al Maraya, Cairo
- Klein, N., 2014, "This changes everything", Simon and Schuster
- Ministry of Environment, 2016, *Third communication*, Cairo
- Ministry of Planning, 2015, *Egypt vision 2030*, 2015
- Pauli, G., "Blue Economy", 2010, Paradigm publications
- Sims, D., 2010, *Understanding Cairo*, AUC press, Cairo
- Sims, D., 2014, *Egypt's desert dreams*, AUC press, Cairo
- Steel, C., 2008, *Hungry city*, translated into Arabic by Fathallah El Shikh, National centre for translation, Cairo
- Toulmin, C., *Climate change in Africa*, 2009, translated into Arabic by Rgab Saad Elsaid, National Centre for Translation, Cairo
- UN, 2010, "Human development in Egypt", UNDP

# Principles for a Successful Riverfront Regeneration with Special Reference to Cairo

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**Abstract:** Cairo with a population of over twenty-one million is one of the densest metropolises in the world. However, its urban population is undeserved with public open spaces; the Nile's riverfront regeneration holds a great opportunity for reconnecting the citizens to their city. By establishing this connection a significant improvement to their quality of life would occur considerably improving their daily lives allowing them a breath out, contributing to their development, providing social equity and strengthening the societal fabric. Although there are some plans and pilot projects for the Nile's regeneration in Cairo, they do not meet the citizens' expectations. The unsatisfactory quality of riverfront regeneration projects can be attributed to the lack of financial support, rules and principles, stakeholder approval and participation. Furthermore, Cairo's riverfronts are facing trends of privatization, abandonment and pollution.

The research attempted to tackle the problem of poor riverfront regeneration principles in Cairo by adapting international design principles to the local context of Cairo. The research followed a deductive methodological approach for data collection and ensured data validation through triangulation of data sources: literature review of design principles, International case studies of riverfront regeneration analysis; as well as carrying out a questionnaire with local experts. The generated list of principles can serve as a guide for future designers, developers and governmental authorities when considering riverfront regeneration for Cairo to ensure a successful and sustainable riverfront regeneration plan.

**Keywords:** Cairo, riverfront, regeneration, principles, sustainable.

## Introduction: Cairo's waterfront

The Nile's waterfront in Cairo is screaming for regeneration, today it is occupied by many uses, formal and informal, residential, commercial, industrial and recreational, but many of such land uses are private developments thus inaccessible for the public who find their refuge in the urban bridges. Although there were and still are many regeneration attempts however in the absence of a specific set of principles to be followed for a successful riverfront regeneration such projects do not reach their objectives, resulting in spaces that don't usually rise to the expectations of the people or meet the desired city image.

In order to bring back the banks to the public; the environmental, social, urban, financial and managerial aspects of the riverfront revitalization need to be addressed, and clear principles are needed to enable urbanists to promote them. Thus to fulfil the basic requirements of the riverfront stakeholders, the research aims at finding a comprehensive set of principles to pinpoint the enabling mechanisms and ensure the accessibility of space along the Nile riverfront.

## Research Methodology

The research uses a deductive methodology to investigate the problem and to meet the main objective of the study see Figure 1. Data is gathered through both primary and secondary methods then analysed in both qualitative and quantitative methods. The

research is divided into three stages, the first stage aims at presenting the literature covering the principles for a successful waterfront regeneration. Then stage two, analyzes successful precedents and reaches another set of principles, finally stage three validates the outcome of the previous two stages through an inductive professionals' survey applied through the internet, assessing the framework on the case study of Cairo's waterfront.

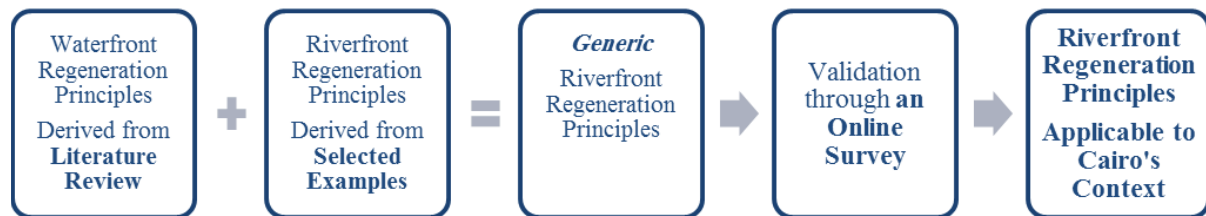


Figure 1. Research Methodology

The research's methodology is designed to triangulate the data collection sources with both primary and secondary sources. Secondary sources are used to analyse the international examples and present selected literature including academic journals, published books, and secondary reports and website material to obtain timely data for the literature and selected examples. The primary sources include the online survey in which it encompassed the verification process for the derived principles of riverfront regeneration.

To validate the principles extracted from literature and successful examples the research developed a questionnaire survey using a 3-point scale 1=least important 2=important 3=most important or NA=not applicable

The target population for the survey are Egyptian urbanists. The sample size was chosen to be 115 respondents. The respondents profile was almost 60% to 40% female to male, and 60% of the respondents' age fall between 21-30 years of age, the survey included experts also of an older age and work either in public, private, or NGOs related to riverfront regeneration projects.

## Background

Urban waterfronts are defined as the magic point where the city meets an element of water, a purely human product colliding with a purely natural component (Hardilova 2012), However Giovinazzi argues that the waterfront should be considered as a web of functions between the coast and the city. The waterfront has to be imagined as a concentration of functions between the port and urban activities that can be productive, cultural, relational, recreational, residential and public. (Giovinazzi & Luav 2008)

Generally a riverfront's lifecycle passes through four main phases starting from the emergence of the waterfront as a point of start for many civilizations followed by the growth and establishment; pursued by the decline of waterfront and finally waterfront rediscovery and awareness (Abdullatip & Shamsuddin 2012).

Waterfront regeneration in specific, under the umbrella of urban regeneration is defined as a term for urban regeneration schemes usually concerned with recovering areas formerly associated with riverside industrial uses such as docks, power generation, and processing industries (Noel. et.al.2013).

Regeneration of deteriorated waterfronts started in America in the 1970s supported by the federal government reconstruction initiatives, followed by the UK in the 80's and since the mid-1980s the vocabulary of waterfront regeneration has been clearly established in the minds of developers, local authorities and national government departments, as the benefits of waterfront location became more apparent (Jones 1998).

Waterfront regeneration is indeed a complex process, a long-term endeavour too. However, the reasons for regeneration differ, or at least the priorities varied in each specific context. The reasons for regeneration included technological changes, historical preservation, rise of the environmental agenda, following the hype of the international agenda, or for the intention of increasing the public space availability (Sairinen & Kumpulainen 2006). What is clear though is that the dynamics of regeneration are directly influenced by the economic context, the more developed, the more mature the regeneration projects are and vice versa, and as explained the process goes through the different stages of: planning, conception, design, construction and post occupancy. This complexity of the waterfront regeneration process is not without challenges. Among such challenges are the sustainability concerns which try to balance out between preserving the environment and the social and economic feasibility of the project - which mandates a mix of land-uses, and a unique identity. Other challenges include the unique location which dictates environmental issues such as working with former industrial sites and working with currently operational waterfronts, finding a character and creatively solving design issues, finally the need for public spaces and the elongated procedures.

### **Principles from Literature**

Today waterfront regeneration is booming for cities to redefine their image (Hradilová 2012). The success of the regeneration depends on the notable qualities and resource efficiency, thus increasing the quality of life (Erkök 2009). Given that water can be used as a collective binding factor that can contribute to a development of an inclusive space, and since that waterfronts can be considered to be a large leisure area (Wang 2000). The renovation of urban waterfronts should be carefully planned while taking into consideration all possible aspects (Sairinen & Kumpulainen 2006).

Several research centers have studied waterfront regeneration projects in an attempt to come with principles for successful regeneration projects and challenges that such projects face. Also some researchers have studied waterfront regeneration projects in-depth and came up with principles for the success and sustainability of waterfront projects.

Some sets of principles established by researchers, waterfront research centers, and forums are studied in an attempt to reach sustainable/successful waterfront regeneration principles. Those sets of principles are compiled as a step to reach a comprehensive tool kit for a successful waterfront regeneration.

The derived principles touch upon environmental, urban, socio-economic, and operational aspects for regenerating waterfronts in an integrated manner. Though the principles are explained separately, it does not contradict that they complement one another see Table 2: Principles for A Successful Riverfront Regeneration, it is noted that not all researchers were aligned in each principle for example unlike the environmental aspect that was listed by all researchers, allowing housing projects was debatable some identified it as an addition and others restricted its development.

## Examples

To endorse the compiled set of criteria, successful examples were analyzed to confirm and enrich those principles, the research investigates international riverfront regeneration projects selected upon, first the success of the regeneration projects according to their international recognition, second the riverfront project being in a major city, third a mega project of 10 km long or more, and Finally that it encompasses public recreational areas see Table 1.

Each project is successful in a specific area according to its concept and was awarded in a view of that. For example Sabramati the closest example to Cairo's context, was awarded the HUDCO National Award for innovative infrastructure development for the Riverfront Project in 2012, as well as the Prime Minister award for the best concept and design of a public project and the most significant award, the USP prize of landmark project. Manzanares was a governmental decision to build a public space; it was awarded the XII Veronica Rudge Green Prize in Urban Design, by the Harvard Graduate School of Design [Harvard GSD]. Newark is a people based regeneration awarded the 2016 award for best implemented plan APA NJ. Finally and Hangang is a unique example of a regeneration over a long period of time.

Some differences were obvious between the projects, the Manzanares uniquely states the importance of moving away the roads and conserving historical structure, Sabramati tackles the issue of enhancing the informal economy, however generally most principles were aligned.

Table 1: Successful Riverfront Regeneration Examples

	<b>Sabramati River Project</b>	<b>Manzanares River Project</b>	<b>Newark, Passiac River Project</b>	<b>Hangang River</b>
<b>Location</b>	Ahmedabad, India	Madrid, Spain.	New Jersey, USA.	Seoul, South Korea
<b>Date</b>	1998-2016	2004	2008	1988-2011
<b>Aim</b>	Redefine the identity of the city as well as give an important waterfront environment by connecting the river and the city and transform the neglected parts of the river bank	Reconnect the river to the urban center by taking the multilane motorway underground and reclaiming the natural landscape for green zones and gardens.	Revive Newark's riverfront and bring concrete benefits to the City of Newark and its residents	Restoration of Ecological Environment and Creation of Economic Potentiality along the Han River.



Objectives	<p><b>Environmental Improvement:</b> reducing the land erosion and flood and plans for cleaning the rivers through the sewage diversion, including water retention and recharge.</p> <p><b>Social Infrastructure:</b> relocating riverbed dwellers and developed activities, parks and public spaces. It also included the provision of socio-cultural amenities for the city.</p> <p><b>Sustainable Development:</b> enabling the sustainability of the project through generation of resources and regeneration of neighborhoods.</p>	<p><b>Phase 1:</b> Calle 30 Project -- The planning and construction of the world's longest urban tunnel, directing the M30 multilane motorway, which formed a ring around the city, underground and installing electrostatic filter ventilation systems to filter the pollution produced by vehicles inside the tunnels.</p> <p><b>Phase 2:</b> Madrid Río Project -- The redesign and implementation of a new linear park along the banks of Manzanares River.</p>	Designing an athletic complex with a walking and biking trail, floating boat dock, bright orange boardwalk, and settings for relaxation, picnics, exercise, and environmental education.	Improving Accessibility, developing the Waterfront Town , Reinforcing Urban Center, Inducing Fine Townscape and Skyline, and forming a Riverfront Park.
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### Compiled Principles

The following table combines the principles gathered from literature and those obtained from the successful examples to find a comprehensive set of criteria. The principles are classified in to four sectors Environmental, Urban, Social and EFM (Economic, Financial and managerial).

Table 2: Principles for a Successful Riverfront Regeneration

		Derived principles from Literature	Derived principles from Examples	Compiled Principles
Environmental	River	Maintain a high quality of water and environmental standards by utilizing innovative technical designs that: enhances the human - environmental interaction, and develops the economic activities of a recreational waterfront, as well as decreasing (pre-existing) industrial pollution. (Breen & Rigby 1994)(PPS 2009)	Adapt with Climate change and design for the protection from flooding and drought, Install Storm tanks to avoid flooding and recycle water, and Minimize the risk of erosion.	Adapt with Climate change and Maintain a high quality of water and environmental standards by utilizing innovative technical designs. Design for the protection from flooding and drought, through Installing Storm tanks, recycling water, and minimizing the risk of erosion.
			Build or improve sewer plants and pipes	Build or improve sewer plants and pipes
			Improve water conditions, Ensure a high Water quality class and that the pollutants are not emptied in the river, and Eliminate the effect of industrial toxins from the water of the river.	Ensure a high Water quality class and Eliminate the effect of industrial toxins and make sure that pollutants are not emptied in the water.

	Ecology		Restore and keep plantation, protect green areas ,And sustain and enhance the ecology of the area (flora and Fauna)	Sustain the ecology of the waterfront (flora and Fiona)
Urban	Accessibility	Ensure public accessibility - both physically and visually - to the water and waterfront. (Abdullatip & Shamsuddin 2012) (Zhang 2002)	ensure public waterfront accessibility on both sides of the river and to all specially people with impairments through diverse modes of access ramps , elevators and stairs	Ensure public accessibility both physically and visually - to the water and waterfront. On both sides of the waterfront and to all specially people with impairments
			design for continuous access through a Continuous trail, and by introducing pedestrian bridges , piers and platforms	Design for Continuous access through a Continuous trail
	Connectivity		Connect both sides of the river through creating overpass bridges for pedestrians and cyclists.	Connect both sides of the waterfront through creating overpass bridges for vehicles, pedestrians and cyclists.
			Renovate directing avenues	Renovate Directing avenues
		Integrate the waterfront development within the surrounding environmental context and urban fabric to contribute to the city's vitality through: creating a waterborne transport system, connecting to the surrounding neighborhoods (and city-center) by fostering an entertainment and a cultural hub.(Zhang 2002)	Improve urban integration between the city center and the districts to the south and west of the city, transforming the River from a barrier into a meeting place for citizens, connecting between neighbors and facilities.	Improve urban integration between the city center and the districts ,transforming the waterfront from a barrier into a meeting place for citizens, connecting between neighbors and facilities.
	City enhancement	Take identity into consideration.	Use the waterfront revival as a start point for the revival and redevelopment of the whole city, and to enhance city identity, and create a memorable image	Use the waterfront revival as a start point for the revival and redevelopment of the whole city, and to enhance city identity, and create a memorable image
			Revitalize waterfront neighborhoods	Revitalize waterfront neighborhoods
			provide adequate infrastructure	Provide adequate infrastructure
			Re-allocate informal waterfront residents and provide them with a permanent residence	Re-allocate informal waterfront residents and provide them with a permanent residence

	Parks and open spaces	Emphasize social connectivity and sustainability of waterfronts by creating parks and green spaces. (Zhang 2002) (PPS 2009) (Wang 2000)	Create waterfront parks and spaces for all (children playing zones, sports zones and parks for elders) along the banks allowing citizens to enjoy nature amidst the urban setting.	Emphasize social connectivity and sustainability of waterfronts by creating parks and green spaces. for all ( children playing zones, sports zones and parks for elders) along the banks allowing citizens to enjoy nature amidst the urban setting.
			Design diverse spaces for special cultural celebrations and occasions such as ecological parks, Design open swimming pools, Design for camping areas	Design diverse spaces for special cultural celebrations and occasions such as ecological parks, Design open swimming pools, Design for camping areas
		Design with regards to urban needs and aesthetics. (Abdullatip & Shamsuddin 2012)	ensure Proper efficient landscape design (seating shading- safety –lighting-plantation),proper urban design , lighting landscape paving ...etc	Design with regards to urban needs and aesthetics. , ensure Proper efficient landscape design (seating shading- safety –lighting-plantation),proper urban design , lighting landscape paving ...etc
			enhance the security of spaces	Ensure the security of spaces
	Mobility		improve mobility, free the city center from traffic, saving in-city traveling times and reducing accidents and offer parking	Improve mobility, free the city center from traffic, saving in-city traveling times and reducing accidents and offer parking
			Move away the road network and Decrease vehicular entry – i.e. underground network	Move away the road network and Decrease vehicular entry to create easy pedestrian access to the public waterfront– i.e. underground network
			Create cycling paths	Create cycling paths
	Transportation	Support multiple transport systems which includes pedestrian and vehicular. (PPS 2009)	Allow multiple modes of transportation and improve the road network, post new signage, provide more pedestrian accessibility via sidewalks. Placing the road underground has created easy pedestrian access to the huge public parkland	Allow multiple modes of transportation, improve the transportation networks, post new signage, provide sidewalks.

	Buildings		prepare guidelines and requirements, covering land use, building bulk, parking, urban design, and public waterfront access., set a regulatory framework of guidelines and requirements for Newark's waterfront redevelopment to ensure a proper benchmark.	prepare guidelines and requirements, covering land use, building bulk, parking, urban design, and public waterfront access, thus setting a regulatory framework for the waterfront redevelopment to ensure a proper benchmark.
		Preserve heritage structures and take identity into consideration. (Breen & Rigby 1994)	Restore historical stone bridges, and reuse historical buildings.	Restore historical buildings for reuse (buildings, bridges, gates... etc.)
	Services and activities	Prioritize mixed uses and create multiple destinations thus encouraging 24 hour activity.(PPS 2009)	design for current and futuristic mixed uses , retail, residential , business and entertainment	Design for current and futuristic mixed uses , retail, residential , business and entertainment, and encourage 24 hour activity.
			Provide the city with cultural, trade and social facilities, And upgrade the current services and make public activities possible	provide the waterfront with adequate services to make public activities possible and use the waterfront for cultural, educational, trade and social uses
			Provide sanitary services.	Provide public washrooms.
		Ensure that buildings are designed to engage people, and serve multiple functions, encouraging iconic building design.		Ensure that waterfront buildings are iconic and designed to engage people, and serve multiple functions.
			ensure proper event management and ground equipped with modern facilities for hosting mega events, such as sports, educational programming, cultural events	Ensure proper event management and design a ground equipped with modern facilities for hosting mega events, such as sports, educational programming, cultural events
			give priority to water related uses , and facilitate for water sports	give priority to water related uses , and facilitate for water sports
	Social	use social media to bring people together and enhance participation, and Have the media coverage in favor of the project thus making it more acceptable by the public		Use social media to bring people together and enhance participation, and Have the media coverage in favor of the project thus making it more acceptable by the public

	engage citizens in the development of the public space, by encouraging participation and providing information	Adopt meaningful public participation in the waterfront scheme development.	Adopt meaningful public participation in the waterfront development, and encouraging participation and providing information
Economic, Financial and Managerial	Regulate and organize vending activities		Regulate and organize vending activities
	built support for the riverfront by taking people on boat and walking tours, hosting outreach events, organizing design education programs for youth, and staging exhibitions.		Built support for the development by taking people on tours, hosting outreach events, organizing design education programs for youth, and staging exhibitions.
	Enhance multiple financing parties or self-financing		plan for multiple financing parties or self-financing
	Introduce a mix of public and private partnership for investments and management (Wang 2000)	Apply public-private partnerships to enhance the operational efficiency of the waterfront development.	Introduce a mix of public and private partnership for investments and management, to enhance the operational efficiency of the waterfront development.
	Develop a plan with all the stakeholders to maximize the benefits and values of the riverfront	Include the original stakeholders in the management of existing waterfront developments.	Develop a plan with all the stakeholders to maximize the benefits and values of the riverfront
	Form a special purpose vehicle for the implementation of the project, to avoid the delays associated with municipal decision making, introduce ease in raising resources, and give implementation efforts a definitive thrust and focus.	Endorse separate organizations or protocols, to ensure that the objectives are realized independent of economic cycles or short term (political) interests.	Endorse separate organizations or protocols, to ensure that the objectives are realized independent of economic cycles or short term (political) interests.
	enhance the informal economy through designing and managing former informal markets		enhance the informal economy through designing and managing former informal markets
	plan focused projects under one big project, through a work breakdown structure (WBS) of the whole project as well as the divergence and convergence of the work paths that would occur in the process		Use a work breakdown structure (WBS) of the whole project to manage the large project and subprojects
		Promote international networking efforts to enhance the waterfront profitability.	Promote international networking efforts to enhance the waterfront profitability.



		develop a masterplan based on analysis however not to the last detail thus leaving room for development, follow a planned control for quality and stage the development i.e. start small to make big changes	Develop a masterplan based on analysis however not to the last detail thus leaving room for development, follow a planned control for quality and stage the development i.e. start small to make big changes
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## Conclusion and Discussion

The process for the verification of the derived principals was based an online survey for the professionals, architects, urban designers and planners. The outline of the survey is as follows, professionals rated each principal 1,2,3 according to its importance to the case of Cairo or NA, if it is of no importance or relevance. Then they were asked to respond to some additional questions, see Appendix A.

The main results derived from the online survey are that there is a general consensus among the prescribed principles with the average scoring of 2.6 – which corresponds to 75% in agreement of the principles. The data was analysed by a weighted average formula for each principle which was given a score out of 3 – 3 being the most important and 1 the least important. The range of individual rating per criteria varied between 68% and 92%.

Additionally, when the respondents were asked to arrange the waterfront regeneration categories, the urban aspects came first, and the branding came last; a case which contradicts the experts' opinion. The most astonishing fact is that there was a discrepancy on how social participation was rated among professionals which means they do not all agree on the importance of social participation in which a plausible explanation can be their uncertainty on how to apply a meaningful participatory method.

Arranged as 1 for the most important and 8 for the least important the following is a representation of the answers.

Table 3: The importance of each factor

	Urban	Environmental	Financial	Managerial	Political	Branding	Social Participation	Economical
1	49	19	3	13	9	5	10	7
2	25	26	13	12	9	6	19	5
3	18	16	22	16	5	5	17	16
4	7	9	25	28	12	6	10	18
5	3	20	23	15	9	11	20	14
6	5	13	13	17	17	14	15	21
7	6	7	11	11	21	24	18	17
8	2	5	5	3	33	44	6	17

The number one challenge perceived by the online population is that of the lack of the political will to carry the project forward, as well the behaviour and attitudes of society to ensure the sustainability of the project.

This is why the answer to the question “Will having a set of criteria for waterfront development help in a better regeneration in Cairo?” - 80% have responded in the affirmative, 5 % responded negatively, and 15% responded as other.

Respondents with “other” wanted to pinpoint the following, yes but with central mandatory policies, A criteria alone will not help unless there is a strategy and willingness to use a criteria for development, Not enough, enforcing regulations and awareness is vital, yes, but tangible funding and strategic planning implementation is needed parallel to this initiative. Yes if there is a sustainable resource of funding beside the government, should help as a regulatory outline but open enough to allow for innovation and protect the essence , To an extent as a guideline not mandatory, But has to have an inspection organization for emphasizing results, execution might be problematic.

The respondents have suggested adding a set of criteria which include: a written regulatory framework for waterfront revitalization projects, as well to raise the level of public awareness. Some principles were related to the environment and included; ensuring the use of sustainable energy sources, introducing environmental awareness to the citizens, and when it comes to urban interventions the principles were missing creating landmarks and program buildings to engage in the public space. Additionally designing green networks connecting between public parks. Respondents recommended some additional social principles including encouraging public awareness and ensuring social class inclusiveness. Finally, financial managerial and political principles that involve, making the project meaningful to the inhabitants, providing jobs and better quality of life for them primarily the touristic issues come next. Encourage sufficient law enforcement to maintain the quality of the space, Guarantee the manifestation of the political will, Ensure the economic validity of the development plans Plan ethnographic studies to understand the users’ needs and behavior to ensure a socially successful plan, Ensure the allowance of appropriate landownership plans and Ensure the collaboration between the stakeholders.

In addition, the results highlighted the necessity to include green corridors with the waterfront regeneration project, and connect the public spaces through a network. The experts also emphasized that a win-win scenario with mutual benefits to all project stakeholders is a must. The surveys highlighted some additional problems and raised some questions concerning the current situation in Cairo. It is clear that there is a divorce between the academia and the authorities when dealing with the Nile riverfronts, which in return causes the construction of undersigned or unsearched regenerations. It is also obvious how much the political and financial aspects are of high importance in Cairo. The experts agreed that the regeneration principles but be tailored case by case and that they all hope for a public, accessible riverfront in Cairo one day.

## **Recommendations**

Based on the research findings on both practical and theoretical grounds a number of research topics were identified and are worthy of research;

Performance evaluation; a checklist of principles for river regeneration projects is a very effective tool for urbanists to come up with a sustainable inclusive design, but those principles would need to be evaluated. How to evaluate such criteria for example is through Key Performance Indicators (KPIs) or benchmarks, to ensure that the criteria are applied. The mechanics of how to make these indicators enforced is embedded through policy making, and that on its own is another field of study.

Stakeholders Mapping; It is quite obvious that there is a multitude of stakeholders, the majority of which governmental organizations, private sector, NGOs as well as global players who shape the waterfront regeneration projects in which. The fragmented decision-making

among institutions needs to be analyzed in order to design efficient institutions that sustain the waterfronts, and are capable of taking informed decisions.

**External Factors;** Undeniably, waterfronts are shaped by external factors, for instance the macro-economic conditions of the context, the political stability or instability of the country, the governance structure, historic natural disasters, the impact of climate change ...etc. Those factors need to be identified and to study the effect for their influence on the water regeneration process.

**Riverfront Segment Conditions;** As pointed out earlier, the riverfronts which pass across different places, and non-homogenous in terms of the specific contextual conditions in which they exist. Thinking of the Nile River as an obvious example, it is not only a national asset, but an international one. It passes through numerous African countries with differing cultures, norms, and urban conditions. Even within the same geographical boundaries of a country, of a governorate, or even of a district; the contextual conditions change, and presumably the set of guiding principles for a successful regeneration project. The parametric changes witnessed by the riverfront, and waterbodies in general, is a valuable topic of research that is worthy of investigation.

## References

- Abdullatip, N.S. & Shamsuddin, S., 2012. International Transaction Journal of Engineering , Management , & Applied Sciences & Technologies Kuala Lumpur Waterfront : A Public Place for All ? , 3(3), pp.311–331.
- Breen, A. & Rigby, D., 1994. WATERFRONTS Cities reclaim their edge, McGraw-Hill.
- Description, G., 2011. the Mega-Blue-Green Network : Madrid River Project.
- Erkök, F., 2009. Waterfronts : Potentials for improving the quality of urban life \*. , pp.126–145.
- Giovinazzi, O. & Luav, V., 2008. Waterfront planning : a window of opportunities for post-disaster reconstruction.
- Handoussa, H., 2005. Egypt human development report 2005, United Nations Development Programme, and The Institute of National Planning, Egypt.
- Hradilová, I., 2012. Influence of urban waterfront appearance on public space functions. , LX(8), pp.261 – 268.
- Jones, A., 1998. Issues in Waterfront Regeneration: More Sobering Thoughts-A UK Perspective. Planning Practice and Research, 13(4), pp.433–442.
- PPS, 2009. Turn Waterfront Around. Available at: <http://www.pps.org/reference/turnwaterfrontaround/> [Accessed October 17, 2016].
- Sairinen, R. & Kumpulainen, S., 2006. Assessing social impacts in urban waterfront regeneration. Environmental Impact Assessment Review, 26(1), pp.120–135.
- Wang, C., 2000. Waterfront Regeneration. , (i), pp.1–24.
- Zhang, L.I., 2002. An evaluation of an urban riverfront park. Washington state university.

## Appendix A: Online Survey Outline

This form is dedicated to professionals and academics in a quest to validate compiled waterfront development criteria gathered from both literature and the analysis of precedents including the cases of Madrid Spain, Ahmadabad India, Newark USA and Seoul, South Korea, as a step towards successfully regenerating Cairo's waterfronts thus solving Social and Urban problems. please rate the following criteria according to their importance, usability and relevance to Cairo's waterfronts to reach a successful sustainable waterfront regeneration.

3 very important    1 least important    NA

			Criteria	12	3	NA
Environmental	Ecology	E1	Adapt with Climate change and Maintain high environmental standards (mitigate the risks of climate change flooding drought and erosion)			
		E2	Sustain the ecology of the waterfront area (Flora and Fauna)			
	water	E3	Comply with water quality standards			
Urban	Accessibility	UA1	Ensure public access to the <b>waterfront</b> area			
		UA2	Enhance public access to the <b>waterbody</b> for water activities.			
		UA3	Guarantee continuous <b>visual</b> access to the view			
	Connectivity	UC1	Connect both sides of the -River- waterfront			
		UC2	Regenerate major streets directing to the waterfront			
		UC3	Encourage unique distinctive building designs to magnet people to the areas			
		UC3'	Program buildings to engage in the public space			
		UC4	Integrate the waterfront development within the surrounding			
	Infra-structure	UI1	Provide adequate infrastructure for the waterfront			
	Waterfront neighbourhoods	UN1	Revitalize waterfront neighbourhoods (eg. Re-allocate/upgrade informal waterfront areas)			
	Users activities	UUA1	Design diverse inclusive spaces eg. Cultural Recreational..etc			

		<b>UUA2</b>	Design with regards to urban needs and <b>aesthetics</b>				
		<b>UUA3</b>	Ensure the security and safety of spaces				
	Mobility	<b>UM1</b>	Enhance non-motorized transport e.g. cycling lanes and pedestrian paths				
		<b>UM2</b>	Design for a continuous trail along the waterfront				
		<b>UM3</b>	Improve the transportation networks, post new signage, and provide adequate parking				
		<b>UM4</b>	Allow multiple modes of transportation				
	Users' services	<b>UUS1</b>	Design for current and futuristic mixed uses and give priority to water related uses (sports ...etc)				
		<b>UUS2</b>	Encourage day and night activities (24 hour activity)				
		<b>UUS3</b>	Provide the waterfront with adequate services, according to the users' needs. i.e. Provide public washrooms				
		<b>UUS4</b>	Provide cultural, trade and social facilities, And upgrade the current services and make public activities possible				
		<b>UUS5</b>	Provide public open spaces by creating inclusive parks				
Social participation		<b>S1</b>	Adopt a meaningful public participation process for the waterfront development, provide information and Build support				
Branding		<b>B1</b>	Use the media to bring people together and have the media coverage in favor of the project				
		<b>B2</b>	enhance city identity, and create a memorable image				
		<b>B3</b>	conserve historical buildings and spaces				
Micro management		<b>M1</b>	Ensure proper event management and design a ground equipped with modern facilities to host mega events				
		<b>M2</b>	Regulate and organize vending activities				
		<b>M3</b>	Enhance the current economy both formal and informal				
Economic-Financial and Managerial (project management)		<b>EFM 1</b>	Seek financing from multiple financing institutions (Public ,Private and NGOs)				
		<b>EFM 2</b>	Introduce a mix of public and private partnership For investments and management				
		<b>EFM 3</b>	Develop a plan with all the stakeholders				



	<b>EFM 4</b>	Endorse separate organizations or protocols eg. SPV special support vehicle ( to ensure that the objectives are realized independent of economic cycles or short term and political interests.)				
	<b>EFM 5</b>	Provide an efficient operation and management scheme for waterfront areas.				
	<b>EFM 6</b>	Use a work breakdown structure (long term development strategy )				
	<b>EFM 7</b>	support Incremental development				
	<b>EFM 8</b>	Promote international networking efforts To enhance the profitability.				
	<b>EFM 9</b>	Develop a masterplan based on analysis, leaving room for development				
	<b>EFM 10</b>	Set and adopt urban guidelines and requirements as a regulatory framework for the waterfront zone to ensure a proper benchmark.				

1. From your point of view are those criteria sufficient for a successful waterfront development in Egypt?
2. If no-Would you like to add any more criterial or other aspects with regards to the Egyptian situation?
3. Rate the following aspects according to their importance to reach successful waterfront regeneration in Cairo?
  - ☐ Environment
  - ☐ Branding
  - ☐ Urban
  - ☐ Social participation
  - ☐ Political
  - ☐ Financing
  - ☐ Managerial
  - ☐ Economic
  - ☐ other
4. Who is responsible for the deterioration of Cairo's waterfronts?
5. Will having a set of criteria for waterfront development help in a better regeneration?
6. What are the expected challenges to waterfront regeneration in Cairo?
7. Will the waterfront development solve the open space problem?
8. Do you have any suggestions for places to act as a start point for a waterfront regeneration project in Cairo?
9. Comments

# Rural Morphology of Nigerian Town: A Quest Towards Ameliorating Challenges in Land Use Activities Patterns

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**Abstract:** A considerable amount of literature has succinctly explained morphology in connection with a critical investigation of human settlement that has developed over time in terms of structure, process, and stages. However, the morphological structural features of rural settlements within the South-west, Nigeria showcased the geographical landscape via identified features that portray their individuality. The characteristic of these settlements is a reflection of natural background, social, historical conditions and human induced activities. Fewer studies have dealt with a morphological examination of a typical Nigerian town in relation with functional and land use activities patterns. Hence, this study explores the neighborhood's growth for the past five decades by establishing diverse rural challenges, features, and prospects. The town is studied in three transformation phases, using ArcGIS version 10.3. The 1st phase spanned between the year 1910 to 1959, while the 2nd and 3rd phases ran through the year 1960 to 1999, and year 2000 to 2015 respectively. Study's objectives are in two folds. First objective is to study the associated challenges with the town through the size, growth, and land use distribution. The second objective is to investigate the perceived inhabitants' activities pattern within the neighbourhood. The first finding revealed that some challenges needed to be resolved in a bid to meet the current basic needs. Second finding indicated that the rural settlements in Nigeria emanated from the residents' adaptation to the environmental conditions, cum transformation through human activities. Meanwhile the third finding established that the human settlements evolved in connection to the local socio-economic, recreation and religious virtues of traditional market place (Oja). Conclusively, the significance of the historical and social influences plays a major role in the solving challenges in the spatial configuration of the settlements. The implication of the study becomes vital to the major stakeholders and professionals in the built environment on the significance of enhancing the sustainable communities in Nigeria.

**Keywords:** Rural morphology, Land use patterns, Rural settlement, Human settlements, Sustainable communities

## Introduction

Recent development in the field of rural and urban design, landscaping, architecture, engineering sociology, urban geography among few have called for proper exploration of neighbourhood and morphology concepts with respect to its size, design, transformation, and planning. Morphology is described as the formation of plots, buildings, use, streets, plans, townscapes (Gordon, 1984). The significance of morphology is reflected largely in that it enables the documentation of spatial aspects of urban and sub-urban developmental viewpoints. In the words, it assist in producing concepts and generalizations related to the character and classification of land use within the sub-urban area, and to the spatial interactions of cities growth, through internal structure and processes (Goodall, 1987; Herbert & Thomas, 1982). In addition, morphology is useful in solving some urban and rural

planning related challenges, and appraisal of features and prospect by the decision makers in the built environment (Whitehand, 1987). Historically, the planning idea originated from Howard's garden city movement (Kallus & Yone, 2000; Spreiregen, 1965) when efforts were geared towards combating problems associated with excessive use of automobiles for daily movement and suburbanization during the 20th and 21st centuries (Nadeem, Hameed, & Zaidi, 2013).

The most useful applications of Geographical information system (GIS) is for planning and management of the land-use suitability mapping and morphological spatial analysis (Brail and Klosterman, 2001; Collins et al., 2001). Notably, the land-use suitability is targeting at identifying the most appropriate spatial pattern for future land uses taken into cognizance the specify requirements, preferences, and predictors of some residents' activities (Collins et al., 2001). Various past studies have adopted the GIS-based land-use suitability analysis in a wide variety of situations including landscape evaluation and planning (Miller et al., 1998), and viable regional planning (Janssen and Rietveld, 1990). In the same vein, plethora of studies have been initiated towards solving neighbourhood related problems such as: improving residents' sense of community, improved residents' social interactions within the neighbourhood, provision of adequate security, improved neighbourhoods' environmental pollution, and health problems (Francis et al., 2012; French et al., 2014; Middleton, 2010; Bonilla 2013; Peter et al., 2010; Song & Knaap, 2003; Broadbent, 1990). Improved general features of neighbourhood lead to the new urbanism that enhances the designing of high density, mixed use walkable, and public transport neighbourhoods to achieve social cohesion and environmental sustainability (NU, 2002; Rubenstein, 1987). A similar concept of eco-towns promotes the designing of environment-friendly neighbourhoods with zero-carbon buildings (Barclay, 2011; Nadeem, Hameed & Zaidi, 2013). Likewise, Berk, (2005) opined that residents' activities and continuous lifestyles formed parts of the basic factors that shape the social environment. This issue was further argued by Meenakshi, (2011) as the causes of segregation in the social environment as against the physical neighbourhood environment.

While affirming the associated landscape challenges in Nigeria, Onwuanyi, (2017); Fadamiro and Atolagbe, (2006); Officha, Onwuemesi & Akanwa, (2012) and Agboola, Zango & Zakka (2015b), submitted that the unplanned land use experienced in most Nigerian neighborhoods has affected the adequacy of the landscapes in diverse ways. Therefore, it becomes imperative in studying the transformations in the physical spatial conditions and development pattern of a typical rural town in Nigeria. This is a view of proffering solution to the associated challenges in land use activities. The objectives of this quantitative and qualitative study focus on the followings: (i) studying the associated challenges with the town through the size, growth, and land use distribution (ii) exploring the perception of the inhabitants (stake holders and professionals in the built environment) on various activities pattern within the town. The two objectives will explore residents' perception about the quality of neighbourhood land use provisions and transformation in physical development of the neighbourhood. Research questions will answer the following: (i) what are the factors that contributed to the transformation of the case study neighbourhood? (ii) Does the quality of the rural setting affect the perception and interaction of community residents? Understanding the existing morphology of a settlement would form a vital factor towards creating an appropriate future developmental intervention. This would, therefore, possess a veritable tool for the rural planning and design in Nigeria.

## Review of literatures

### *Rural neighbourhood morphology*

Rural morphology dwelt with the various forms of historical approach in relation to the developmental processes of diverse historical periods. The approach explains in details the relationship between the social processes and the observed physical development. An environment where community residents live is surmised into natural, artificial, and social areas (Aydin & Büyük, 2014). It is argued in this study that the artificial environment relates to the physical environment as evolved by the human requirement that changes overtime. The social environment is coined as places meant for human social interactions. And lastly, the artificial environment is the one influences man-made features such as buildings, roads, and other land features. According to Zhang and Li, (2012); Ariane et. al., (2005) neighbourhood environmental characteristics consists of accessibility, amenities, sociability, aesthetics, safety, and policies. The characteristics of which can either to enhance or discourage people's perception and influenced by usage, shared experience, and gainful opportunities derived (Kazmierczak 2013; Peter, et. al., 2010). Thus, neighbourhood constitutes essential components that provide natural and cultural features to improve community infrastructure, a social status which invariably promote neighbourliness (Gobster, 2001).

However, literature suggests that a neighbourhood unit should be socially and environmentally sustainable in terms of provision and location of residential accommodation, public facilities, commercial areas and utility services (Bramley & Power, 2009; Dave, 2011). In the same vein, neighbourhood planning should have its aim rooted in the provision of essential amenities capable of enhancing ethnic's interactions and maximum utilization. Shaping attributes of the neighbourhood in multi ethnic groups should constitute an equal right of access, right of use and equal ownership or control (Megalhaes, 2010). Meanwhile, the rural neighbourhood composed of diverse open green spaces allowing recreational, religious, social, aesthetic, psychological and economic activities (Kaymakli, 1990; Akinci, 1996; Yildiz, et al., 2011, Agboola, Rasidi & Said, 2015a). The morphological changes manifest in terms of the social, environmental and economic context that showcased the effect of human cultural actions which culminated to the formation and transformation of neighbourhood built environment.

### *Rural neighbourhood Land Use Characteristics and Features*

The rural services and facilities could be categorized as primary and secondary. Primary services and facilities include a general food store, post office, bank, libraries, health center, and green space such as village green, green street edges. Others include public toilets, public seating, and transport stops. The secondary services and facilities include open spaces like market squares, parks, and recreation grounds, and community facilities such as a stadium. Other includes road lighting systems, traffic signals, domestic water systems, sanitary sewer systems, parks and recreational facilities, public schools, police and fire protection buildings. These are essential elements useful in providing a livable community, transformations, and enhancing the quality of life (Massam, 1993).

Two groups of services are iterated by Jenks and Jones, (2010). The first group represents indispensable elements called infrastructures such as transportation (streets and roads networks), water supply networks, sanitation, drainage, solid-waste management, electricity, and telecommunication. The second group includes urban services and facilities such as educational, health, commercial, industrial, administrative, cultural, religious, social

services and green space. Winter and Farthing, (1997) identified local neighborhood services and facilities in the United Kingdom context, and iterated the compositions of a food shop, post office, pub, supermarket, primary school, and open space. Other services that need frequent access include a chemist, restaurant (Burton, 2000a), bank or building a society (Barton et al., 1995) and community center (Dempsey et al., 2009). Empirical study has reinstated that the environment is capable of encouraging peoples' physical activity (Goldstein, 2002). According to Onibokun, (1973), a neighbourhood in Nigerian context encompasses physical, social and psychological variables. Consequently, the neighbourhood acts as meeting and connection place make a significant contribution towards fostering community identity, social interactions, and community revitalization. In another perspective, the characteristics and features of neighbourhood possess an ideal place for communal interaction (Aydin and Büyük, 2014). The Nigerian neighbourhood transformation before and after colonialization has affected by people's culture in the society in recent time. Consequently, the physical and social characteristics could help concretising a proper understanding of the built environment which has affected the socio-cultural structure of the economic and general conditions of villages.

### **Research method, measurements and data analysis**

For planning and management, the most commonly used applications of GIS are the land use suitability mapping and analysis (Brail and Klosterman, 2001; Collins et al., 2001; Herzele & Wiedemann, 2003). On a wider scope, land-use suitability analysis through the GIS application has the potential to provide a useful monitoring tool towards the use of neighbourhood green spaces and their changes (Herzele & Wiedemann, 2003). Similarly, the procedure is capable of appropriating adequate spatial pattern for future land uses in a bid to establish specify requirements, preferences, or predictors of some activity (Hopkins, 1977; Collins et al., 2001). Morphology is often used to present the changes in the physical and spatial transformation of land mark features in landscape architecture. It has helped in depicting a graphical representation of neighborhood changes and enables the calculation of the time wise increase in area spatial expansions. This study adopted morphological method as carried out by past studies of some scholars such as Chen (2011); Na et al., (2009) and Doralti (2004).

Three periods were considered in this study namely: colonial period of pre-independence (the year 1910–1959); the post-colonial period after independence (the year 1960-1999), and modern movement in landscape architecture (the year 2000 -2015). The analysis procedures included (i) gathering, collection, and updating of existing features and elements of the neighborhood through on-spot assessment, (ii) the maps were produced based on the time wise periods and digitized by using AutoCAD software (version 2012). The digitizing was done for the purpose of exporting into the ArcGIS version 10.3 for subsequent mapping, (iii) the maps was super imposed to deduce the changes in the spatial development and features. In line with the previous study of Malczewski, (2004); geographic information systems were used to determine the various land-uses of the neighbourhoods such as (i) areas covered by the market square as commercial zone, (ii) residential and government coverage areas, (iii) educational institution coverage areas, (iv) religious coverage areas, and (v) green and open space coverage areas. The procedure adopted for the evaluation of the neighbourhood land-use areas of the case study town. Summarily, the



examination is based on the physical form of the town, taken into cognizance the link between the physical form and socio cultural context. The mapping of the neighbourhood is a systematic approach targeting the identification and classifications of a community's cultural resources (Rowe, 2012).

Perceived neighborhood characteristics and preferences parameters were adapted from Handy et al., (2004). The study adopted a quantitative research method using relative Importance Index (RII) to analyze the collated data using a Likert scale. The parameters considered includes (i) rating of the present conditions of the neighbourhood and adjoining land features encourages easy accessibility (human and vehicular access, RPN1), (ii) rating of the present conditions of the neighbourhood that encourages safety via quietness and low crimes [RPN2], (iii) rating of the present condition of the neighbourhood that encourages interactions (socialization) among all groups through provision of benches, walkways etc [RPN3], (iv) rating of the present condition of the neighbourhood that encourages peoples' attractions through the level of its cleanliness, housing styles and streets' green landscapes [RPN4], (v) rating of the present conditions of the neighbourhood that encourages lots of off-street parking such as garages and drive ways [RPN5].

Respondents (Stakeholders and professionals in the built environment residing in the community for more than two years) were purposively sampled and requested to rate their level of agreement or disagreement with the series of [5] statements on a five-point scale from strongly disagree [1] to strongly agree [5]. Relative Important Index (RII) was appropriately used to cross-compare the relative Importance index among the perceived constructs by the respondents. The formula adopted for relative importance index (RII) is in line with past studies of Agboola & Salawu (2015) and Agboola, Rasidi & Said, (2017) as follows:

$$RII = \frac{\sum fx}{\sum f} \times \frac{1}{k} \quad \text{--- . . . . . eqn. 1}$$

Where:

- RII = Relative importance index
- $\sum fx$  = the total weight given to each attribute by the respondents
- $\sum f$  = the total number of respondents in the sample
- K = the highest weight on the Likert scale which is 5

## Study areas

The geographical location of the South-Western Nigeria as depicted in Figure 1 lies between the parallels 5.86° and 9.22° North, and between 2.65° and 5.72° East with an estimated area of about 181,300 km<sup>2</sup> (Atanda, 2007). South West Nigeria has six states; Ekiti, Lagos, Ogun, Ondo, Osun, and Oyo. It is majorly a Yoruba speaking area, although there are different dialects even within the same state. The weather conditions vary between the two distinct seasons in Nigeria; the rainy season (March – November) and the dry season (November–February). The dry season is also the bringer of the Harmattan dust; cold dry winds from the northern deserts blow into the southern regions around this time. Ijebu-jesa

as the case study neighbourhood lies on Latitude: 7° 40' 57.61" N, Longitude: 4° 48' 51.70" E. Ijebu-jesa is the capital of Oriade Local Government area in the Osun State of Nigeria. It is a commuter city with connections to Ekiti State on one side, Ondo State on another and it has a border with the famous Ilesa the area of the surrounding town Iwoye-jesa, Iloko-jesa, Ere and Ijeda.

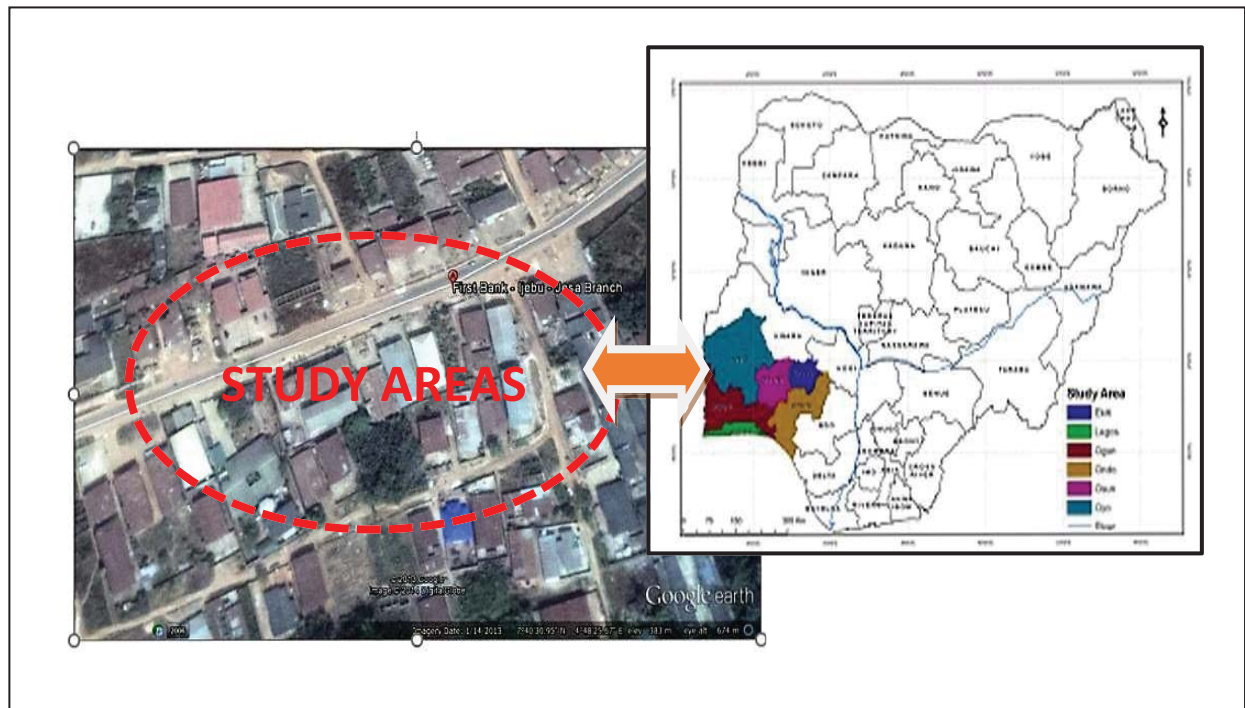


Figure 1: Map of the study areas and its position in the Nigeria. Source: Google map

## Results and discussions

### *The transformation in the town's size, growth and land use distribution system*

The nature of planning during the ancient period was such that it was undertaken by traditional leaders in consultation with community members based on their social-economic needs. The developments were in form of haphazard with crooked and irregular lanes ended up at wide open space at the centre of the settlement. The open spaces were used as market places (oja) and meeting grounds for deliberations on community issues. This early development comprised sub-divided compounds and occupied by related lineages were in clustered form with small lanes and streets in between them. The rationale for such spatial configuration was to protect the inhabitants from external aggression. Humans operate on various tangible and intangible elements of cultural dimensions. Figure 2; identify the comparison in the land use for the three transformation periods of the Ijebu-jesa built form.

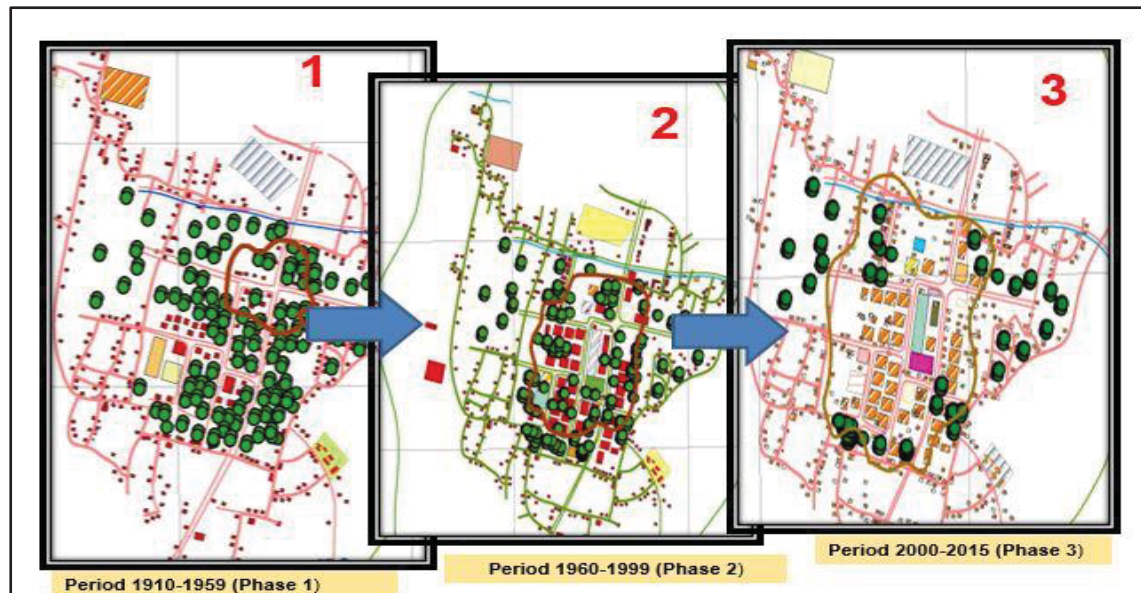


Figure 2: comparison in the land use for the three transformation periods of the Ijebu-jesa built form

#### *Period 1910-1960 (Phase 1):*

This historic period covers almost fifty (50) years of existence of the town. Meanwhile, the period is classified as pre-colonial and colonial periods of the open space's planning in Nigeria (Oduwaye, 1998). At the same time, this period is associated with the existence of traditional landscape. The spatial characteristics of this period associated with the existence of about 2.62 km<sup>2</sup> (4.74%) of both the residential structures and government structures (Figure 3). The greatest greenery and open space areas of 48.92 km<sup>2</sup> (88.41%) were available during this period as shown in Figure 4. In view of this, the location of the market square (Oja) and shrine (ojubo-orisa) at the core of the neighbourhood created cluster types of settlements pattern. There were no planning concept and expertise at this period, as the pace setters and founders were King (Oba), chief (Oloyes), and the community residents. Therefore, the coverage area of the market square (Oja) was about 1.04 km<sup>2</sup> (1.88 %) with virtually no spectacular facilities (Figure 5). Hence, the general level of development of the neighbourhood was at lowest ebb as shown in Figure 2. It is noteworthy to state here that there was virtually little or no human and vehicular congestion at this period.

#### *Period 1960-2000 (Phase 2):*

The period of 40 years refers to a postcolonial period, after independence associating with researchers' awareness on industrialization, urbanization, planning, and preservation (Falade 1989; Oduwaye 1998; Oyesiku 1998). While others include an appreciation of open space greeneries. Historically, the industrial revolution seems to have negative and devastating effects on the environmental landscape during this transformations period. Therefore, this period informs peoples' awareness of the interaction between man and nature, which brought open space planning concept. This equally acted as a bridge between

the past and present-day relationships between the society and its environment (Rescia et al., 2008). Similarly, scholars began to advocate the need for the establishment, management, planning, and design of landscape and built environment in general. Figure 2 and Figure 6 revealed an increase in the percentage of land use features due to the following factors. First was the incorporation of private residential, religious (church and mosque) and commercial structures (banks, shops, eateries etc) which led to a reduction in green space from 48.92 (88.41%) of phase one to 39.92 (61.07%) phase 2. This phase 2 reflect (i) increase in the percentage of the new religious structures [Figure 8] and educational structures [Figure 7], (ii) increase in areas occupied by market square (Oja) to about 1.83 km<sup>2</sup> [2.80 %] from 1.04 km<sup>2</sup> [1.88%] experienced between Year 1910-1959 as shown in Figure 5. (ii) Increase in road and street networks and connectivity [Figure 4].

Hence, it obvious that a drastic change of environment and physical character exist at a higher proportion than the former base map features (Figure 2 and Figure 6). In addition to this, reduction in the percentage of greeneries has affected the human appreciation of open space beautification. This was also traceable to the increase in the population of the community residents at this period. According to the 1991 census (the Final result of 1991 National population census of Nigeria), the population of Ijebu-jesa was 11,680. There was an increase in the population by the year 1996 projected population to about 13,314 indicating an increase of about 12.27 % (Agboola, 2016).

#### *Period 2000-2015 (Phase 3):*

The period spans through fifteen (15) years, which solidified the advent of the modern movement in landscape planning and management in Nigeria. The appropriate consolidations of ecological approach towards landscape management were initiated. Also, advocacy was intensified on concern for landscape as cultural heritage. Researchers such as Falade (1989); Oduwaye (1998); Oyesiku (1998); and Adejumo et al., (2012) advocating and taking cognizance of the interrelationship between the people and their environment. Consequently, the increase in the awareness of scholars on the significance of the landscape qualities, design, and management in Nigeria is noted at this period.

The above scenario led to the general debate on the term sustainable development, which could be in form of physical or social developments. This period is experiencing an upsurge in residents' population of about 22,499 (the year 2015 projected population) amounted to about 40.82% (Agboola, 2016 and Figure 3). It is obvious that greater percentage of the green areas seen in phase 1 of development that spanned years 1910 to 1959 and that of phase 2 between years 1960 to 1999 have been taken over by residential, educational and commercial structures (Figure 2). This led to a reduction to about 28.48 km<sup>2</sup> (32.09%) in of the land use coverage by the green space and open space areas in phase 3 of the neighbourhood development (Figure 3 and Figure 6). In other words, the expansion/urbanization has further created more spaces for (i) area covered by market square as commercial zone with 2.04 km<sup>2</sup> [2.30%], as depicted in Figure 5, (ii) area covered by residential structures and Government structures with 29.02 km<sup>2</sup> [32.75%] as depicted in Figure 3, (iii) areas covered by educational institutions with 16.38 km<sup>2</sup> [18.45%] as shown in Figure 7, (iv) religion coverage areas with 12.29 km<sup>2</sup> [14.41%] as revealed in Figure 8.



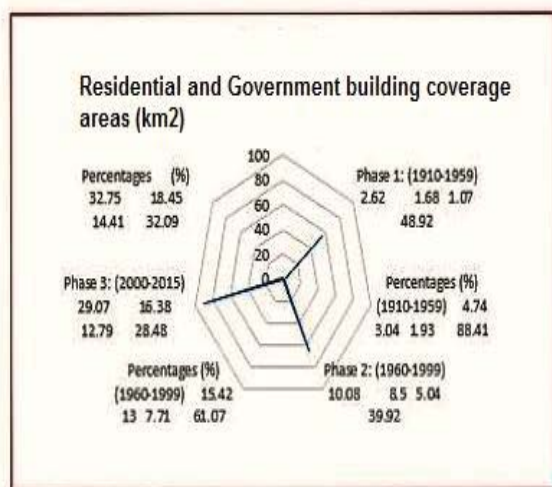


Figure 3: Land use coverage by the residential and Government structures

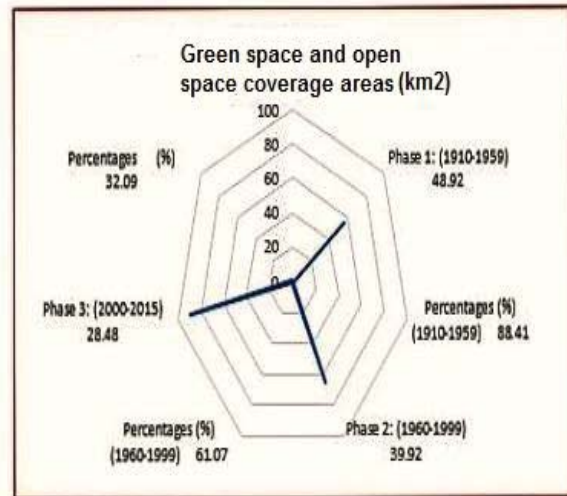


Figure 4: Land use coverage by the green space and open space areas (Km<sup>2</sup>)



Figure 5: Land use coverage by the market square (oja) in Km<sup>2</sup>

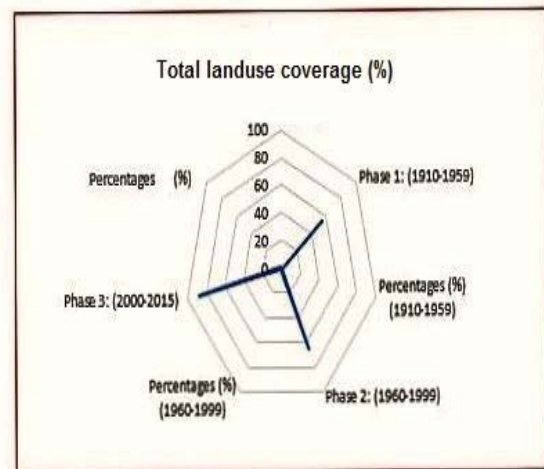


Figure 6: Total land use coverage (%)

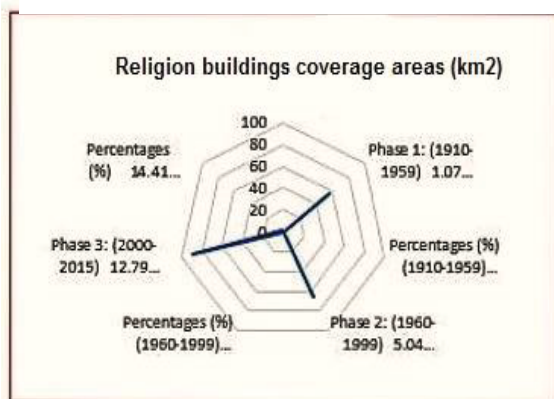


Figure 8: Land use coverage by the religion structures (Km<sup>2</sup>)

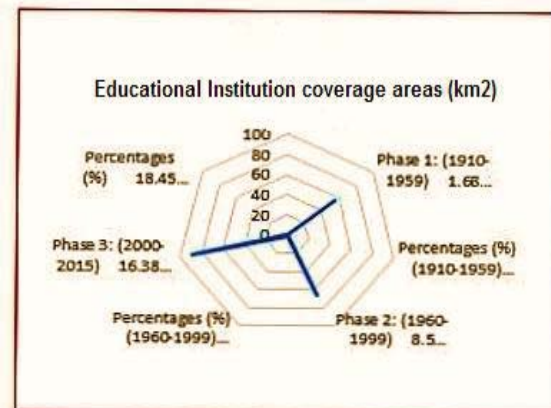


Figure 7: Land use coverage by the educational structures (Km<sup>2</sup>)



### *Perceived inhabitants' activities on the neighbourhood characteristics and preferences*

The non-parametric results of a total number of 18 collated survey questionnaires were reflected in Figure 9 and Table 1. The mean and the relative importance index (RII) analysis presented the followings: (i) respondents' accessibility to the neighbourhood [RPN1] exhibited mean value of 4.61 and relative importance index of 0.92; (ii) neighbourhood safety [RPN2] revealed a mean values of 4.11; and relative importance index of 0.82; (iii) respondents' socialization within the neighbourhood [RPN3] showcased a mean values of 3.77 and relative importance index of 0.76; (iv) respondents' perception of neighbourhood attractiveness [RPN4] depicted a mean values of 3.11 and relative importance index of 0.62; (v) neighbourhood spaciousness via the adequacy of market square conditions and green infrastructures [RPN5] showed a mean values of 2.27 and relative importance index of 0.45.

From the aforementioned, accessibility to the neighbourhood ranked 1st indicating inhabitants gave the highest priority in appraising the suitability of the neighbourhood in the provision of excellent vehicular and pedestrian accessibilities. In other words, the neighbourhood accessibility has been considered in this study as an important aspect of sustainable neighbourhood development, particularly in the social well-being dimension as supported by past study of (Lynch et al., 2011). Accessibility remains the basic requirements to meet residents' free entry thus tends to enhance residents' quality of living (Lau and Chiu, 2003; Landry and Chakraborty, 2009). More importantly, accessibility was identified as an important aspect of environmental determinants for residents' physical activity. Ranked 2nd was the neighbourhood safety. The security and safety available in the neighbourhood space influence the quality attached by the residents. This is in line with the previous study of McCormack and Shiell (2011) in which the residents' safety is considered vital in the overall neighborhood design.

Socialization within the neighbourhood signified interactions among the diverse ethnic residents. Thus, it is ranked 3rd in the hierarchy. The result of the survey demonstrated that the neighbourhood forms could allow interaction among residents. Due to the low ranking, it is expected that an improvement is needed in the provision of adequate benches, walkways, seat out among others. This is corroborated by the researchers in the field of urban design and planning in which neighbourhood space established as an essential ingredient for social interaction and daily life experience (Madanipour, 1992; Worpole, 1992; Calthorpe, 1993; Pasaogullari and Doratli, 2004). The outcome of the analysis placed respondents' perception on neighbourhood attractiveness 4th in the rank. The attractive appearance of the neighborhood could be judged in terms of the level of upkeep, variety in housing styles and street landscape, settings and fittings (Sallis, Bauman, & Pratt, 1998). Similarly, it relates to the perception of the physical judgment of neighbourhood by the residents via its aesthetics.

However, the low ranking in the residents' perception in this respect suggests a need for an improvement and proper maintenance. Advocacy for proper neighbourhood facilities and amenities would better enhance its beauty and attractiveness. Last on the ranking was 5th that was ascribed to residents' perception on the neighbourhood spaciousness via the provision of the well landscaped market square and green infrastructures. The lowest ranking indicates that much effort is needed to enhance neighbourhood spaciousness. The design and planning of neighbourhood open spaces remain a vital factor in its accessibility. Meanwhile, the spatial design of neighbourhood open spaces and its accessibility influence people's choice (Landry and Chakraborty, 2009).

Table 1: Result of the perceived inhabitants' activities on the neighbourhood characteristics and preferences

Variables	Codes	Frequencies of response					$\Sigma f$	$\Sigma fx$	Mean	RII	Rank
		5 (Strongly Agree)	4 (Agree)	3 (Neutral)	2 (Disagree)	1 (Strongly Disagree)					
Accessibility to the neighbourhood	RPN1	14	3	0	0	1	18	83	4.61	0.92	1st
Neighbourhood safety	RPN2	12	2	0	2	2	18	74	4.11	0.82	2nd
Socialization within the neighbourhood	RPN3	9	4	0	2	3	18	68	3.77	0.76	3rd
Level of neighbourhood attractiveness	RPN4	5	4	1	4	4	18	56	3.11	0.62	4th
Neighbourhood spaciousness (market square and green infrastructures' provisions)	RPN5	3	2	0	5	8	18	41	2.27	0.46	5th

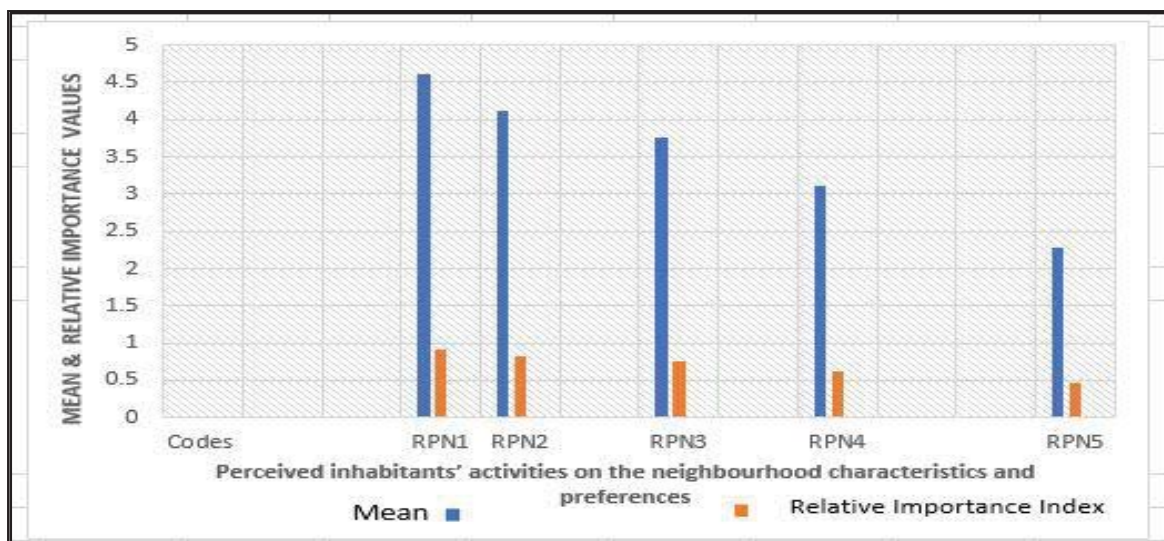


Figure 9: Perceived activities on the neighbourhood characteristics and preferences.

## Conclusion and Recommendation

The study fills the knowledge gap by identifying the morphology of a rural neighbourhood as showcased by the residents' perception and character favoring future rural planning and design in Nigeria. Additionally, the combination of quantitative and qualitative of this study through relative importance index and the GIS-model allows documentation of neighbourhood comparative studies in Nigeria. The uniqueness of this study is that, it depicted rural landscape information that intertwine with social information on a neighbourhood level, which allows for a better insight into the various deficiencies in Nigerian rural setting. Each transformation period was intertwined with driving forces such as accessibility, urbanization, and globalization. Meanwhile, the challenges associated with every phase were as a result of the nature of the rural neighbourhood, the pace of the changes, and peoples' perception of the landscape. In other words, the quality of neighbourhood spaces impacts on citizens' patterns of activities. This study approach encircled the classic relationship between people and the sustainability of the

neighbourhood environment as a means of enhancing residents' well-being and social needs. As established in this study, the social fragmentation of the rural landscape, however, is given not enough attention. The major originality of this research lies in the attempt to bridge a gap between the quantitative and qualitative study of rural neighbourhood towards the future design and planning practice. This research thus recommends adequate planning and design of neighbourhood and its adjoining spaces by the professionals and other relevant stakeholders for neighbourhood inhabitants in Nigeria. The knowledge gained from the outcome of the research could be made operational as an integrated monitoring tool that could be adopted by the three levels of government (local, state and federal authorities) in Nigeria.

## References

- Adejumo, T., Okedele, N., & Adebamowo, M. (2012). Symbolism in the Conceptualization of Contemporary Yoruba City Central Business District Urban Design. In *Architecture and Urban design proceedings* (Vol. 3, pp. 967–976). Epoka. Retrieved from [www.icaud.epoka.edu.al](http://www.icaud.epoka.edu.al).
- Agboola, O. P., Zango M.S. & Zakka S. M. (2015b): Towards Sustainability of Open Space's Planning and Management in Nigeria: Roles of Science and Technology". *JurnalTeknologi*. Vol.27, No 14. Pp 51-56.
- Agboola O.P. (2016). Rural Sense of Community of Oja in Nigeria. Unpublished Ph.D. Thesis Submitted to Universiti Teknologi Malaysia.
- Berk, MG. (2005, October). Concept of neighbourhood in contemporary residential environments: An investigation of occupants' perception. Paper presented at the International Conference on Doing, Thinking, Feeling Home, Delft, The Netherlands. Online at <http://mpra.ub.uni-muenchen.de/22481/>.
- Boblic, (1990). *The Role of Time Function in City Spatial Structure Past and Present*, Gower Publishing Co Ltd, UK, p.25-51.
- Bonilla Mauricio Hernández (2013). The significance and meanings of public space improvement in low-income neighbourhoods 'colonias populares' in Xalapa-Mexico. *Habitat International* 38. Pp 34-46.
- Brail, R.K., Klosterman, R.E., (2001). *Planning Support Systems*, ESRI Press, Redlands, CA. Briassoulis.
- Bramley, G. & Power, S. (2009). Urban form and social sustainability: the role of density and housing type. *Environment and Planning B: Planning and Design*, 36, 30-48.
- Commonwealth Department of Communications and the Arts (1995) *Mapping Culture* (Canberra, Commonwealth of Australia).
- Dave, S. (2011). Neighbourhood density and social sustainability in cities of developing countries. *Sustainable Development*, 19, 189- 205.
- Duxbury N. and Campbell, H. (2011). *Developing and Revitalizing Rural Communities Through Arts and Culture*. Small Cities Imprints, 3 (1).
- Fadamiro, J.A., and Atolagbe, A.M.O (2006). Urban Environmental Sustainability: A Challenge to Effective Landscaping in Nigeria. *Dimensi TeknikArsitektur* 34(1), 44-51.
- Falade, J. B. (1989). Amenity and Open Space Planning in Nigeria. *Land Use Policy*, 162–171.
- Francis, J., Giles-corti, B., Wood, L., & Knuihan, M. (2012). Creating Sense of Community: The Role of Public Space. *Journal of Environmental Psychology*, 32 (4), 401–409. doi: 10.1016/j.jenvp.2012.07.002.
- French, S., Wood, L., Alexandra, S., Giles-corti, B., Frank, L., & Learnihan, V. (2014). Sense of Community and Its Association with the Neighborhood Built Environment. *Environment and Behavior*, Vol.46 (6), 677–697. doi:10.1177/0013916512469098.
- Goodall, B. (1987). *The Penguin Dictionary of Human Geography*, Hariviondsworth: Penguin
- Gordon, D. (1984), "*The Shaping Of Urban Morphology*", In D. Reeder (Ed. ), *Urban History Yearbook* 1984,, Leicester: Leicester University Press, Pp. 1-10.
- Herbert, D. and Thomas C. (1982), *Urban Geography*, Chichester: John Wiley.
- Onwuanyi, N. (2017). Remaking Nigeria's Urbanism: Assessing and Redressing the Dearth of Open Spaces in Benin City. *International Journal of Built Environment and Sustainability*, 4 (2), 121–130. <http://doi.org/10.11113/ijbes.v4.n2.183>.
- Pillai, J. (2013). *Cultural Mapping: A Guide To Understanding Place, Community, And Continuity* (1st edition). Petaling Jaya: Malaysia: Strategic Information and Research Development Centre, Universiti Saints Malaysia.

## Collective analysis for Cairo's food system flows towards deriving physical planning and policy guidance.

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**Abstract:** Food security is one of Egypt's fundamental challenges for development and human welfare. Egypt has suffered a series of shocks that caused an evident decline in its food and nutrition security and problems as poverty and food insecurity that were usually perceived as rural issues are becoming a rising concern for urban areas as well. Cities are bound to food by their appetite. Yet, as urban dwellers, we are oblivious to what it takes for our urban food systems to function and the amount of resources needed to feed our cities. The complexity and low visibility of urban food systems have hindered addressing them in the same magnitude as other urban challenges. However, urban food systems are directly related to the city's economic development, public health and welfare of its residents. An insight into the metabolism of our urban food system; where the city is reread as an ecosystem where flows of energy and materials cross, can help us manage its complexity and contribute to its sustainable development. Taking Cairo as a case study; six vital food system flows are identified: land, water, energy, goods, capital and employment. The flows are to be analysed both quantitatively; to visualize the system's transfers and losses and spatially; to illustrate how the flows relate to the city's spatial development. The data is to be analysed in terms of: the food system resource use, environmental impacts and inefficiencies and the system's food security, in terms of the food availability and access dimensions. The paper will then reflect on how to relate Cairo's food systems to the Egyptian city-development policies and physical planning process; based on the previous analysis and the best planning practices on food systems and sustainability discussed in the literature.

**Keywords:** Food security, Urban Food Systems, Sustainable development, Urban Metabolism, City Flows.

### Introduction

Food is considered to be a complex adaptive system; in that it is dynamic, consist of multiple interconnected elements and can change corresponding to learnt experience (Gupta, 2012). Food systems need to be addressed through a holistic approach that integrates the social, economic and environmental aspects that accompany their consumption, rather than through a traditional sectorial approach. The research aims to provide a comprehensive analysis on Cairo's food system in terms of the system's needs and resource use, challenges and inefficiencies environmental impacts, and food security through its food availability and access dimensions; towards deriving a set of policy and physical planning guidelines that attempt to minimize the system's losses and maximize its returns for its sustainable development.

## Urban Food Systems

Food systems can be defined as: “i) all the activities related to the production, processing, distribution, consumption and disposal of food, ii) all the factors affecting its activities as: environment, actors, infrastructures and institutions, iii) the outcomes of these activities that contribute to food security and a range of socio-economic and environmental issues” (HLPE, 2014), as shown in Figure 1. A comprehensive approach to what constitutes an urban food system starts from defining the set of actors and activities along the food system chain that shapes the structure and dynamics of the food system; that in order to be sustained require a group of inputs in the form of flows; classified into natural resources flows represented in land, water and energy and socio-economic flows represented in goods, capital and employment. The notion behind the system’s flows was inspired by the IABR project for the city of Rotterdam and what constitute each individual flow, as shown in Figure 2, was inspired by CAPMAS annual reports on the various economic activities related to the food system. These set of activities and flows have outcomes on the environmental level contributing to land use, water quality, emissions and biodiversity levels and on the social level contributing to food security, health and nutrition. The food system also functions within larger super systems that direct the system’s behaviour represented in food policies, how the system is governed and the socio-cultural environment in which the system exist.

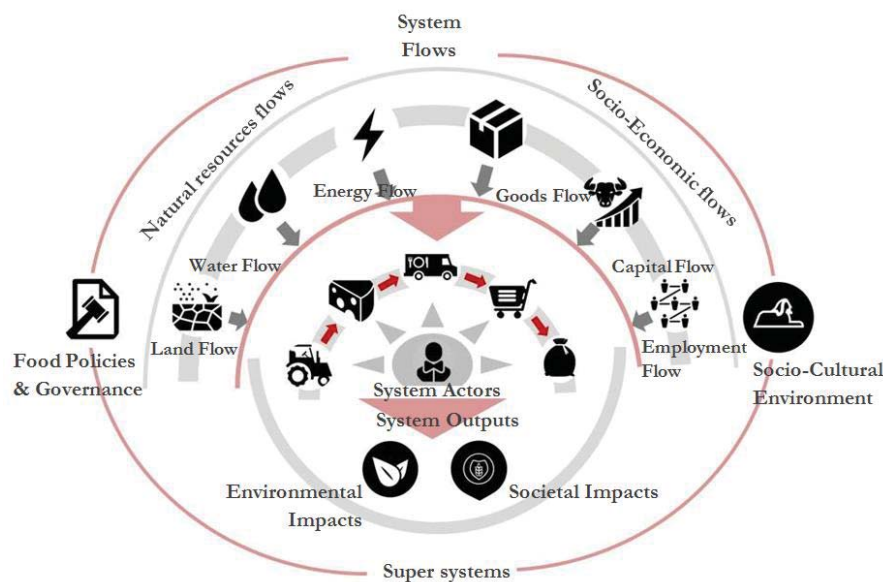


Figure 1 Urban Food System, Source: Authors.

## Research Methodology

The coming section will explain the used research methodology; in terms of the applied data collection and data analysis methods.

### Research setting and Study population

To help achieve a comprehensive understanding; the analysis was done on two levels; the national level represented in Egypt and the regional level represented in Cairo governorate; whose administrative boundaries are defined according to the 2016 CAPMAS Egyptian geospatial information portal. The national scale is to be used as a frame of reference to help understand the volume of contribution that Cairo’s food system shares on the national level and the variations in the performance of the different flows along the national and regional levels.



## Data collection methods and Sources of information

Due to the lack of direct available data related to the food system activities; the required data were calculated from CAPMAS annual statistical reports on agricultural, industrial, commercial and environmental activities, on both Egypt and Cairo levels, with the aid of the case study's demographic and statistical data as population numbers and several design standards data books as Neufert's third edition. The research also used the 2012 Cairo's strategic plan report by the General organization of physical planning-GOPP when creating the spatial maps for Cairo's food system flows.

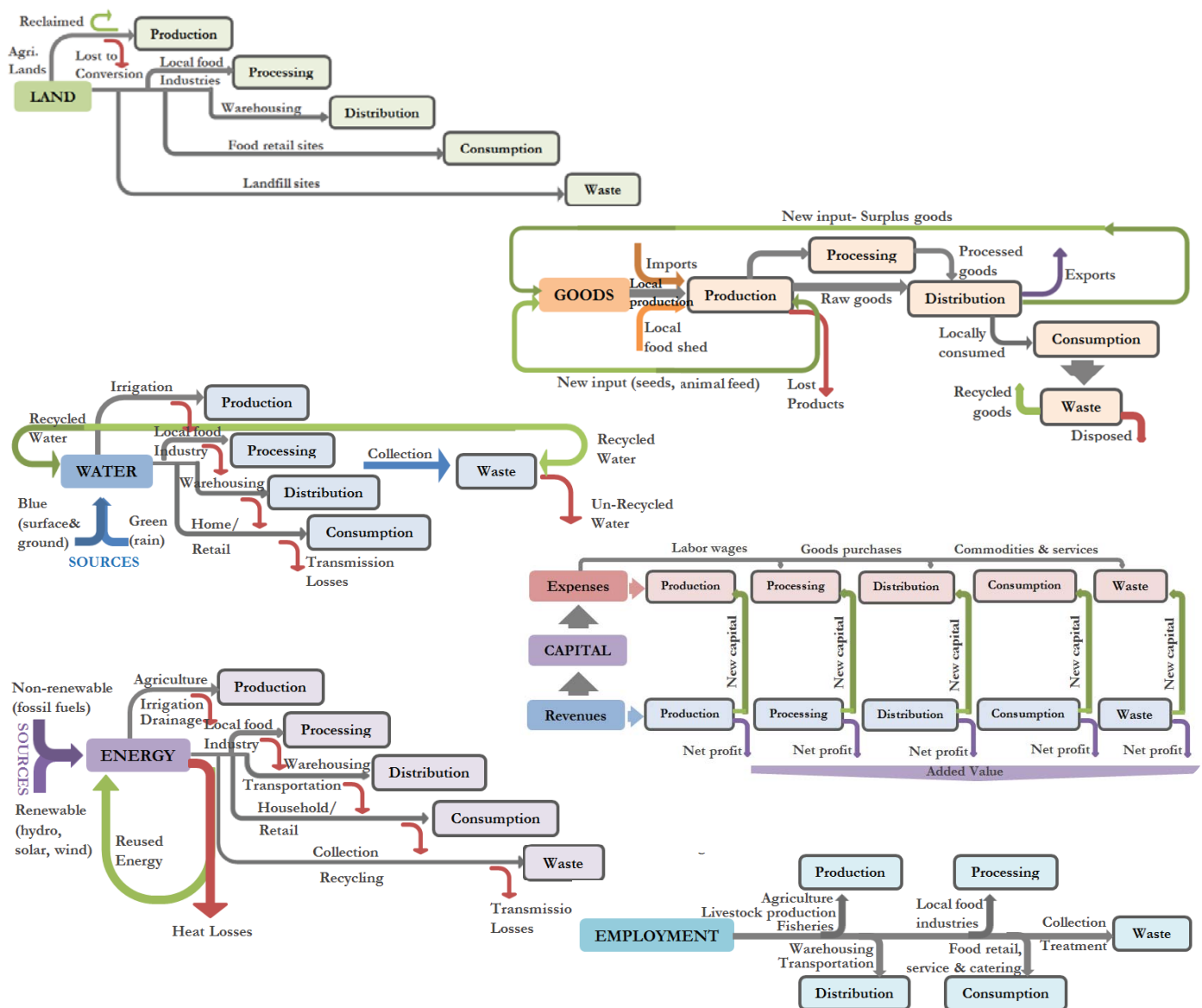


Figure 2 Urban Food System Flows, Source: Authors.

## Data Analysis

### Thinking in flows for sustainable urban development

Responding to urban challenges can no longer be conducted through traditional approaches; thus new paradigms of thinking are needed to understand how cities function. The applied approach rereads urbanization as an ecosystem; where flows of materials and energy cross;

working on connecting and coupling these flows to reduce losses and increase efficiency (Sijmons, 2014). Very little is known about what it takes for our urban food system to function. An insight into the metabolism of the urban food system in Cairo can help it work towards a more sustainable future; through better understanding of planning and managing its complexity (Kennedy, 2010). Six vital food system flows are identified: Natural Resources Flows; represented in land, water and energy and Socio-Economic Flows; represented in goods, capital and employment. The Flows and their consequences were examined to determine the fields of inefficiencies and look for potential synergies that can be turned into future opportunities and how they relate to the city's spatial development.

### Mapping Flows

Sankey flow diagrams are graphical representations of the dynamic relationships in a system; through illustrating the structure and interaction of its constituting elements; visualizing the transfers, efficiency and nature of losses within a system (Harris, 1999). As the research will be examining flows in different units: land in feddan, goods in tonnes and capital in L.E, etc. and in order to unify these flows into quantities that could be related and compared to each other, the units will be converted to percentage format. The six defined flows will be analysed according to the five main activities that constitute an urban food system; production, processing, distribution, consumption and waste, as shown in Figure 3 and the produced Sankey diagrams will be accompanied by a spatial analysis of the study area-Cairo.

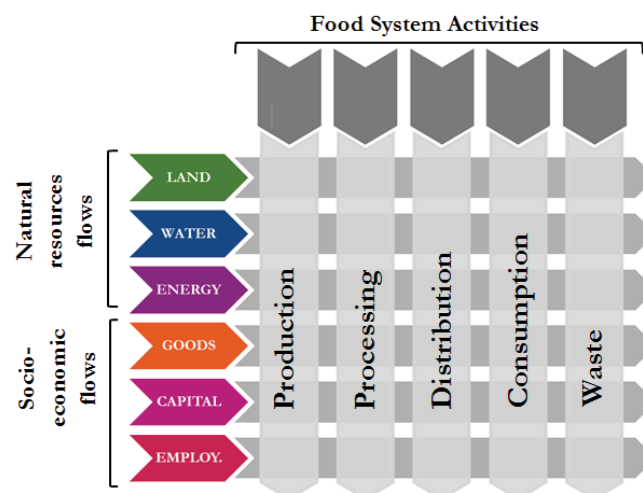


Figure 3 Methodology of the flows analysis, Source: Authors.

### Results and findings

The data analysis was conducted for each individual flow, followed by a collective analysis of the six identified flows in terms of: the food system resource use, environmental impacts, challenges and inefficiencies and the system's security; to provide an insight into the current local food system situation in Cairo Governorate. The findings on the presented challenges and inefficiencies of Cairo's food system have been summarized in Table 1 and Table 2 below; applying the six identified food system flows, in relation to the five main food system activities.

Table 1 Collective analysis for Cairo's food system challenges and inefficiencies (production, processing and distribution phases), Source: Authors.

FOOD SYSTEM FLOWS	PRODUCTION PHASE
LAND	- Loss of lands to urban conversion and unplanned growth. Guidelines establishing urban and rural fringes are vaguely defined and manipulated.
	- Extremely limited arable land area available to food production in the governorate. Insufficiency of local food production and increasing dependency on food imports from neighbouring governorates and abroad.
	- Production lands constitute the highest share for the food system land needs on both the national level and Cairo's level; 99.6% and 75% respectively.
	- The Egyptian food system lacks an efficient knowledge system on the available and required agricultural resources; that can result in conflict of policies, inadequate farming decisions and food gaps.
WATER	- Cairo relies almost solely on the Nile river water; by 96%, for its food system water needs. - All water services are provided by the public sector on both Egypt and Cairo levels.
ENERGY	- Cairo relies solely on fossil fuel energy for its food system energy consumption. - Energy services are almost solely provided by the public sector; by 99.8%, with minimal involvement of the private sector.
GOODS	- Locally produced goods constitute the least share among traded goods (1.1%); where the governorate relies mostly on imported goods from neighbouring governorates (69.2%) and foreign imports (29.5%).
CAPITAL	- Farmers are financially stressed and unable to compete with other forms of development, in the face of increasing economic and social pressures as increasing land values, decreasing agricultural economic spin-off and bias against agriculture in urban areas. - Urban food activities are under constant pressure of losing their right in cities to conversion to other forms of residential and commercial development. - The production phase constitutes only 0.6% of the food system capital value; where Cairo relies more on the revenues generated from the consumption and food retail sectors rather than the production sector.
EMPLOYMENT	- On Cairo's level, the production phase accounted to only 8.4% of the total food system employment, due to the consuming nature of the governorate.
FOOD SYSTEM FLOWS	PROCESSING PHASE
LAND	- Food processing is under the threat of losing industrial lands in cities, in face of residential and commercial development.
FOOD SYSTEM FLOWS	DISTRIBUTION PHASE
LAND	- Pushing agricultural lands away from urban areas means food is travelling further distances; increasing food costs, city congestions and pollution.
WATER	- Transmission losses through the various food system activities severely affect the efficiency of its water flow. They constitute large shares of water loss; 17.96% on the national level and 28.75% on the governorate level.
ENERGY	- 59% of the energy input is lost as heat losses, in addition to 5.25% of the input lost in transmission; mounting to a total loss of 64.25% of the energy input, before reaching the various food system activities.
GOODS	- 12.3% of the total goods input are lost to spoilage and transmission losses before being processed or consumed.

Table 2 Collective analysis for Cairo's food system challenges and inefficiencies (consumption, waste and governance phases), Source: Authors.

FOOD SYSTEM FLOWS	CONSUMPTION PHASE
LAND	- Studying food outlets distribution in Cairo shows uneven distribution especially in low income areas and centralized food access in new urban communities; creating food deserts and increasing food insecurity.
WATER	- Cairo's highest share for water needs is in the consumption phase; constituting 42.9% of the total water use.
ENERGY	- Cairo's highest share for energy needs is in the consumption phase; constituting 27.7% of the total energy use.
CAPITAL	- The highest share for the food system expenses is recorded in the consumption phase on both the national and governorate levels; 53.5% and 76.2% respectively. - The consuming nature of the governorate and dependency on food imports causes loss of economic opportunities for the local community, increases food expenses and decreases the food system revenues; decreasing its total added value below the average national levels; (National: 75%, Cairo: 18.6%).
	- The Egyptian food market suffers from price distortions among different geographical regions and between rural and urban areas and price volatility due to the dependence on international imports and the Egyptian pound devaluation against the USD. - Several governmental institutions are involved in consumer protection which can create overlaps and conflicts. Consumers and businesses lack of awareness with the consumer protection mandate.
	- The Egyptian food subsidy program suffers from low quantity and quality stocks, is expensive to operate; requiring third of the Egyptian budget and is poorly targeted.
EMPLOYMENT	- The highest employment share is recorded in the consumption phase (64%); as Cairo relies almost solely on food retail rather than food production sector.
FOOD SYSTEM FLOWS	WASTE PHASE
LAND	- Waste landfills belong solely to the public sector, however unofficial random disposal sites can often be found around the city. - The land sites are designated for mainly dumping activities; where composting and recycling activities rarely take place within the governorate.
WATER	- Only 4% of the water input is recycled and turns back to the system as new input. Thus, the majority of the used water in the food system (96%) is either lost in transmission or disposed of.
GOODS	- Only 6% of the goods input are recycled and return back to the system for reusing.
EMPLOYMENT	The least employment share on both the national and governorate's level was recorded in the waste phase; 1% and 3.6% respectively.
GOVERNANCE & DEVELOPMENT PLANS	
	- Comprehensive development plans that directly or indirectly address food systems in cities have not yet been devised for Egyptian cities.

## Recommendations and policy advice

After briefing on the research findings and results, this part will reflect on the research recommendations and policy advice for Cairo's food system; based on the previous analysis and principles and best planning practices on food systems and sustainability discussed in the literature, as shown in Table 3, Table 4, Table 5 and Table 6.

Table 3 Recommended physical planning and policy guidelines for Cairo's food system (production phase), Source: Authors.

FOOD SYSTEM FLOWS	PRODUCTION PHASE
LAND	- Distributing the governorate into a series of transitioning zones from rural to urban; with an established set of planning guidelines for each zone with regards to building densities and percentage of natural to built environment; to help preserve rural areas and obtain a balanced relation between urban and rural environments. Inspired by the Transect theory, (Andrés, 2003).
	- Diversifying urban food production models in city development plans; in both horizontal urban expansion settings, as in suburbs; using peri-urban agriculture models as: farming units, yards gardens, rights of way and vertical urban expansion settings, as in compact urban areas; using space intensive models as: roof tops and vertical farming techniques; accommodating to the available space. Inspired by le corbusier's radiant city, Wright's broadacre city and Havana's urban agriculture experience (Corbusier, 1987), (Wright F. L., 1958), (Murphy, 2005).
	- Establishing a National urban agriculture program in cities to promote education, training and national conscious towards urban agriculture systems and provide research and technical assistance to urban agricultural units; providing services as: extension agents and cooperative agriculture assemblies (Gonzalez, 2000).
	- Establishing a robust food knowledge system that provides an accurate data base on agricultural resources as: land parcels, land quality, production rates, etc. and assists farmers in managing their farms according to national priorities.
	- Providing policies that facilitates the applying of urban farmers for land and the practice of urban farming on either state enterprises as: city owned parks and rights-of-way and reclaiming underused urban spaces as car parks and brownfield sites for growing food, or self-provisioning enterprises on private properties as private residential parcels and backyards.
WATER	- Integrate more resource efficient water usage techniques as agricultural & waste water treatment and water desalination activities. Storing rain water in times of surplus; to be used in dry seasons in productive and recreational landscapes.
ENERGY	- Introduce new measures to integrate renewable energy sources as solar and geothermal energy sources, into the power grid; to help achieve a more sustainable and resource efficient energy system.
CAPITAL	- Implementing urban agriculture models especially in underserved communities, for its potential to provide empowerment, in terms of providing job opportunities, income and accessible local food, with shorter supply chains (Unger, 2006).
EMPLOYMENT	- Allocating further employment opportunities in the local food production sector in both state and private enterprises to decrease the governorate's food dependence and food expenses. - Ensuring further integration of the private sector in service provision activities to reach balanced shared responsibilities among both sectors.



Table 4 Recommended physical planning and policy guidelines for Cairo's food system (processing and distribution phases), Source: Authors.

FOOD SYSTEM FLOWS	PROCESSING PHASE
LAND	- Circular food industries: establishing comprehensive circular food industries; through integrating seedling industries with farming, food production, processing and food packaging in a closed cycle, with other supplementing industries as plant-based pharmaceuticals; where the output of one industry is the input of another; for maximized resource use efficiency and minimal food waste. Inspired by circular economy business models (OECD, 2002).
	- Conscious land zoning policies that acknowledge food industries as local non-polluting industries; essential to the development and welfare of the community and whose proximity to urban areas is cost efficient and environmental friendly (Jones, 2005).
WATER	- Service provision: allocating food industries in proximity to required services and infrastructure: as water, energy, transportation and infrastructure for better exchange and provisioning conditions.
ENERGY	
CAPITAL	- Policies that integrate food processing industries in the local economy through a diverse array of large, medium and small sized enterprise and verified in their provided services from processing, preparing, packaging and trading food.
FOOD SYSTEM FLOWS	DISTRIBUTION PHASE
LAND	- Land zoning policies that provide sufficient storage and warehousing spaces and markets for local food distribution activities within the city, efficiently connected to the required transportation and infrastructure.
	The integration between food production and distribution activities to shorten and strengthen supply chains; through alternative food distribution models as farmers markets, farm to table models and community supported agriculture programs; that directly connect local producers to consumers. These models are cost efficient for both producers and consumers provide more local economic opportunities and are environmental friendly (Jones, 2005).
ENERGY	- Integrating urban food production models to reduce energy use due to their small scale production that reduces machinery needs and decreased transportation due to proximity of production sites. - Applying shorter supply chains as farmers markets and farm to institution models for reduced transportation & energy consumption (Unger, 2006).
GOODS	- Diversified food transport network: boosting the quality of goods flow; through developing a diversified and well integrated transport network for goods distribution; comprised of motorized (delivery vans, cargo lockers and pickup points) and water transport.
	- Cargo hubs: reducing freight traffic that passes through the city's urban centers to avoid congestions and delays and directing it away to inner and regional ring roads, along which the city's cargo hubs are strategically allocated; benefiting from the goods flow to generate added value. Inspired by IABR Rotterdam project (IABR, 2014).
CAPITAL	- Implementing local and urban food production models with shorter supply chains that decreases food expenses and are cost efficient for both producers; who obtain increased direct revenues and consumers who obtain decreased food costs (Unger, 2006).

Table 5 Recommended physical planning and policy guidelines for Cairo's food system (consumption phase),  
Source: Authors.

FOOD SYSTEM FLOWS	CONSUMPTION PHASE
LAND	- Mapping food system's coverage: To ensure adequate food access; mapping food outlets and their service zone coverage should be applied as a prerequisite to spatial planning. Food outlets mapping can be examined in relation to population densities, poverty distribution and public transit routes distribution within the city (Cassidy, 2008).
	- Neighborhood design: including the allocation and distribution of food outlets as a design consideration in neighborhood design; allocating 400m walking distance for high access areas and 800m walking distance for low access areas and ensuring better distribution through corner shops and small variety stores in a mixed use setting, rather than agglomerated shopping complexes, segregated from residential areas (Unger, 2006).
	- Land zoning policies that utilizes the economic, social and cultural potential of food retail in revitalizing neighborhoods in both large commercial centers and small neighborhood streets (UNEP, 2016).
WATER	- Consumer awareness activities that attempts to influence consumption patterns to more sustainable choices; in terms of dietary habits, resource use and food waste, as a lever towards change to a more sustainable and resource efficient food system.
ENERGY	
GOODS	- Transport planning: including the distribution of food system outlets as a factor in cities transport planning; taking into consideration how consumers are to reach them either by walking, using public transit or private vehicles within the assigned coverage distances. - Developing a transport loop that connects citizens to the city's boulevards and public markets for an enhanced shared space and mixed urban environment (IABR, 2014).
CAPITAL	- Egyptian food market: i) Further monitoring to tackle price dispersion and hikes with better integration between the different institutions involved in consumer protection under a unified plan (IDSC, 2013). ii) Executing advocacy activities for both consumers and businesses; to clearly set out the rights and responsibilities towards consumer protection (IDSC, 2012).
	- Egyptian food subsidy program: i) Updating the food subsidy program database and restructuring its operating guidelines to efficiently target vulnerable households. ii) Ensure efficient distribution of consumer complexes and provision stores, especially in underserved neighborhoods. iii) Increasing dependence on local food commodities rather than imported commodities to obtain stable and sustained supply and decrease the program's expenses (IDSC, 2013).

Table 6 Recommended physical planning and policy guidelines for Cairo's food system (waste and governance phases), Source: Authors.

FOOD SYSTEM FLOWS	WASTE PHASE
LAND	- Extracting raw materials from waste and food flows through integrating waste recycling and reuse activities in food production, industries and consumption; to successfully close the food system loop and reduce its losses (IABR, 2014).
	- Provide taxes reduction and reduced service provision expenses for industries and businesses that implement recycling and reuse activities. Implementing strict laws on industries and businesses that perform random and hazardous disposals in river and inner city sites (CIWMB, 2006).
	- Policies that aim at reducing food waste and resource use along the food system inputs, through a number of prevention strategies: ensuring efficiency in the production and consumption phases and increasing public awareness on food waste, sustainable disposal and recycling activities. (UNEP, 2016).
WATER	- Further Integration of agriculture and waste water treatment techniques in the food system water use.
ENERGY	- Channeling energy waste; through shifting from individual heat production in households and businesses to developing a stable heating network grid of heat hubs that couples between generated and residual heat and control cascading to various demands in the city; reducing energy consumption and CO2 emissions. The generated heat energy can be reused in various industrial and heating activities across the city (IABR, 2014).
GOODS	- Edible food recovery: cutting down the food system's waste through the integration between food system activities; by connecting food outlets as restaurants and grocery stores with food banks and charitable feeding organizations; to sustainably regulate food surpluses and support individuals that cannot meet their basic food needs (Cassidy, 2008). - Segregated waste collection: facilitating its implementation by designing a segregated sewage system that transport the collected organic waste to protein collectives; that can be used later on in urban farming (IABR, 2014).
CAPITAL	- Allocating further capital resources to the food waste sector to ensure a more sustainable and resource efficient food system.
EMPLOYMENT	- Allocating further employment opportunities in the food waste sector in collection, composting, recycling and reuse activities.
GOVERNANCE & DEVELOPMENT PLANS	
<p>- Addressing food systems comprehensively in the governorate's development strategies; through one of the following modes, (UNEP, 2016):</p> <p>i) Food policy council: comprised of representatives of the food system segments within the community as: farmers, retailers, NGOs, as well as governmental officials; working together towards establishing a more just and ecologically sustainable food system. They exist outside government structure and have an advisory function through research, advocacy and community education with a food system focus.</p> <p>ii) Department of food: dedicated to local food issues and setting public and private programs to enhance the community's food security.</p> <p>iii) City planning agency: part of the government planning agency that acts as a starting point towards integrating urban food systems with other urban systems and benefit from the existing databases on various community indicators to analyze and formulate policies and programs related to the local food system.</p>	

## Conclusion

In terms of the food system needs; the production phase constitutes the highest share of resources use on the national level, however, on Cairo's level, the consumption phase constitutes the highest share of resources use; asserting the consuming rather than productive nature of the governorate. Thus, the need to implement design strategies that aspire to reduce resource use for the same economic input use as circular food industries, diversified food transport networks and alternative distribution models with shorter and strengthen supply chains. In terms of the system's losses and inefficiencies; around third of the system's water input, more than half of its energy input and 12.3% of its goods input are lost before usage and only 4% of the total water input and 6% of the goods input are recycled to be reused in the system as new input. Thus, the need for devising design strategies that address the systems' inefficiencies and maximize its returns as improved infrastructure and services provision, resource recovery and raising awareness to more resource efficient consumption patterns. Cairo's local food production is insufficient to fulfil its demands and the governorate relies mostly on food imports from the neighbouring governorates and foreign countries. This can be traced back to the extremely limited arable land area in the governorate, loss of lands to urban conversion and unplanned growth; where farmers are financially stressed and unable to compete with other forms of development. Thus, urban conscious land use and zoning policies that protect agricultural resources and integrate food system activities successfully in urban settings are strongly needed; as transitioning zones, integrating food production in city development plans mapping food system's coverage for better food access and including the allocation and distribution of food outlets as a factor in cities transport planning and a design consideration in neighbourhood design. Working towards the integration and balanced share of responsibilities along its different actors is crucial for the success of the system, along with an efficient food knowledge system that allows integration and coordination among the food system elements, to avoid conflict in policies and ensure adequate decision making. Food systems have not yet been addressed in Egyptian urban development plans and it is needed to devise a mode of governance dedicated to local food issues to formulate policies and programs with further consideration to the food system on the urban agenda.

## References

- Andrés, D. (2003). *The New Civic Art: Elements of Town Planning*. New York: Rizzoli International.
- CAPMAS. (2014). *Annual Statistical Reports*. Cairo: CAPMAS.
- Cassidy, A. (2008). *The Planner's Guide to the Urban Food System*. University of Southern California School of Policy, Planning, and Development.
- CIWMB. (2006, March). *Innovations' Case Studies: Food Waste Recovery - General Information*. Retrieved September 19, 2016, from General Information: Food Waste: <http://www.ciwmb.ca.gov/LGLibrary/Innovations/FoodWaste/Program.htm>.
- Corbusier, L. (1987). *The City of Tomorrow*. New York: Dover Publications.
- Gonzalez, R. (2004). *THEORIES, MODELS AND URBAN REALITIES: From Newyork to Kathmandu*. Leon.
- GOPP. (2012). *Cairo's strategic plan report*. Cairo: GOPP.
- Gupta, A. (2012). *Insights from Complexity Theory: Understanding Organisations better*. Bangalore.
- Harris, R. L. (1999). *Information Graphics: A Comprehensive Illustrated Reference*.
- HLPE. (2014). *Food losses and waste in the context of sustainable food systems*. Rome: High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security.
- IABR. (2014). *Urban metabolism, sustainable development of Rotterdam*. Rotterdam: IABR project atelier Rotterdam.

- IDSC. (2012). Towards building a national strategy for managing food security issues in Egypt. Cairo: IDSC.
- IDSC. (2013). Egyptian food observatory: Food Monitoring and Evaluation System. Cairo: IDSC.
- Jones, P. (2005). COLLABORATIVE FOOD SYSTEM ASSESSMENT. San Francisco: San Francisco Food Systems.
- Kennedy, S. P. (2010). The study of urban metabolism and its application to urban planning and design. *Environmental Pollution*, 159: 1965–1973.
- Murphy, C. (2005). CULTIVATING HAVANA: Urban Agriculture and Food Security in the Years of Crisis. FOOD FIRST, DEVELOPMENT REPORT No 12.
- Neufert, E. (2000). Neufert Architect's Data. Backwell Science.
- OECD. (2002). Measuring material flows and resource productivity. Paris: The OECD Guide Glossary, Vol.
- Sijmons, D. (2014). Urban by Nature. Rotterdam: International Architectural Biënnale Rotterdam.
- UNEP. (2016). Food Systems and Natural Resources . A Report of the Working Group on Food Systems of the International Resource Panel.
- Unger, S. (2006). A FOOD SYSTEMS ASSESSMENT FOR OAKLAND , CA. California: University of California, Department of regional planning.
- Wright, F. L. (1958). The Living City. New York: Horizon Press.



# The Role of the Spatial Configuration in Land Use Distribution in Muscat

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**Abstract:** This study examines the relationship between land use distribution and the spatial structure of street networks in the newly developed neighbourhoods in Muscat city, Oman. Two neighbourhoods in Al-Maabilah district in Muscat were examined using Space Syntax theory. The land use maps were developed through exhaustive site visits. While axial line maps of Space Syntax were generated using DepthMapX Software. The spatial attributes included in the study were Integration, Control, Choice and Normalized Least Angle Choice (NACH); whereas the land use variables were Retail, Residential and Mix-use. The relationships between the variables were assessed statistically using SPSS software. The results showed that the distribution of the Residential land use is significantly influenced by the spatial attributes in highly intelligible spatial configurations; with NACH being the best predictor of the distribution of the Residential land use followed by Integration. However, in areas with low intelligibility the correlation was not significant. In addition, the degree to which an area has a formal grid structure was found to have no effect on the relationship between the variables. Thus, this paper contributes to Space Syntax literature and land use distribution studies by providing evidences on how the spatial arrangements might influence land use distribution; and concludes with recommendations to the planning authorities in Oman.

**Keywords:** Land use, Space Syntax, Street network, Oman, Integration, Normalized Least Angle choice.

## Introduction

Land use is one of the most important factors that determine how active an area is. Many factors influence land uses such as social, economic and spatial factors (Hong-Kyu and Dong, 2002). In this study, we focused on the spatial factors in order to explore whether the spatial configuration of the street network in the newly developed districts in Muscat, Oman, affects the land use distribution. Accordingly, this research attempts to provide answers for the following questions:

1. How does the spatial configuration affect the land use distribution in the newly developed areas in Muscat?
2. Is there a relationship between the spatial configuration of the chosen neighbourhoods and their land use?
3. Does the spatial properties of the neighbourhood as whole influence the relationship between land use distribution and spatial attributes?

In order to answer these questions, two areas were selected in a newly developed district –i.e. *Al-Maabilah*– in Muscat with different densities and land uses. The maps of these areas were obtained from Muscat Municipality, and the land use data was acquired through exhaustive site visits. The plans were used to conduct Space Syntax analysis, namely axial lines, using DepthMapX software. Then, the land use data and the spatial data were used to conduct correlational analysis using SPSS program.

Although the relationship between street configurations and land use distribution has been widely studied, most of the studies in this area focused on one type of land use or activity, mainly retail activities or office buildings. To the authors best knowledge, this issue has not been yet studied in Oman and hence the significance of this study. In addition, this study uses a proven theory, namely Space Syntax and its Axial Lines method, to provide

meaningful information about the spatial configuration of the street network in the selected areas.

### ***Literature Review***

The sultanate of Oman witnessed a major development since the Renaissance in 1970, which led to a rapid urban expansion in all parts of the country. This development was funded mainly by the government. Cities, mainly Muscat, has been expanding since then to meet the demand of the population growth which increased from 740,000 in the first half of the seventies to 4,170,556 by the end of July 2015, with most of the population concentrated in the Governorate of Muscat. This led to urban expansion and development of new areas away from densely populated areas on a large scale in order to accommodate this massive population growth in the capital. As a result, the urbanization was spread to the outskirts of Muscat. The emergence of the new areas in Muscat led to the need of studying its spatial configuration during its development phases in order to adjust the expansion and properly control it according to population needs (Abdulfatah, 2015).

In spite of the awareness of the importance of understanding how the urban expansion is occurring in Muscat, most of the research related to the built environment in Oman focuses on energy sources (Kazem, 2011), sustainability (Saleh and Alalouch, 2015) and eco-architecture (Alalouch et al., 2016). An exception of this is a recent study done by Alkamali and her colleagues in which they investigated the effect of the expansion of Muscat city on the accessibility to the old historical core using Space Syntax theory (Alkamali et al., 2017).

At the international level, several research investigated how land use is distributed according a several factors. For example, Hong-Kyu and Dong (2002) analyzed the relationship between land use density of office buildings and urban street configuration using Space Syntax and Axial lines. The research covered two urban areas of traditional and contemporary layouts. It was found that the land use density is affected by the urban street configuration. The paper concluded that the new area has higher values of connectivity, control and global and local integration. Kim and Jun (2013) conducted a wide scale study with a focus on residential and commercial land uses in Seoul. Land use density was calculated using building area and floor area of the buildings whereas street structure was measures by the global integration of the axial line. Then correlation analysis was conducted for both land use density and land price. The study found that when the length of the road is taken into account, the integration has significant correlation with the land use density and land price.

In another study, Lerman and Omer (2016) examined four areas in Jaffa (Tel Aviv) in the occupied Palestinian territories with two different urban layouts, traditional and contemporary. These areas were analysed with the focus on four dimensions that have potential influence on pedestrian movement and distribution: (i) a spatial dimension based on road network structure; (ii) a functional dimension of land uses such as retail fronts; (iii) a physical dimension of road sections; and (iv) a demographic dimension of population and employment densities. The findings of this paper showed significant differences between adjacent traditional and contemporary sub-areas. Traditional sub-areas have higher levels of spatial connectivity and retail fronts distribution and higher pedestrian movement volume. The spatial dimension has the strongest overall connection to pedestrian movement, for traditional sub-areas, while the physical dimension has the strongest connection to pedestrian movement for the contemporary sub-areas.

Similarly, Lamíquiza and López-Domínguezb (2015) examined four urban areas. These areas were categorized into traditional and contemporary urban types. The results showed the influence of three indexes on the pedestrian activity: density, land use and accessibility to the public space network. In a more recent study, Koning *et. al.* (2017) used space syntax Spacematrix, Mixed-Use Index and property ownership data to analyse the central areas in Bergen, a city in Norway, to discover how the urban transformation takes place in a natural way. They found that the degree of street network integration affects the location of commercial activities and the degree of building density and function mix.

These studies suggests the existence of relationships between street configurations and land use density and/or distribution in several areas of the World. In fact, these studies support Bill Hillier (1996) theory on “city creation process” in which he suggested that network structure shapes flows and movement, and through this, it shapes land use patterns, leading the city, through feedback and multiplayers, to evolve. According to Ye and Nes (2013), the maturation of cities is dependent on the street configuration, which will cause the land use to change in order to adjust with the current integration values of the streets.

Lee and Kim (2009) in their review of the literature on land use found that earlier studies on this topic could be grouped into two categories: Analysis of the direct relationship between land use and land price, and exploration of the effect of the spatial configuration characteristics on land use and land price using Space Syntax. Several studies that belong to the second category have found correlation between some of the spatial attributes that Space Syntax measures and land use and commercial land value, see for example (Desyllas, 2000), (Min et al., 2007), and (Seok and Lee, 2008).

In fact, Space Syntax’s ability to describe the spatial relationships in a quantified way provided a powerful tool to the research community to explore how space design effects certain behaviour and consequently predicts the functional consequence of the design. According to Alalouch (2009), Space Syntax community have provided evidences showing strong correlations between Space Syntax measures and pedestrian movement, land use and value, vehicle movement in urban areas, crime pattern, space occupancy rate, privacy in hospitals. Therefore, this study employs Space Syntax methodology to explore the relationship between land use distribution and street configuration in the newly developed areas in Muscat, Oman.

## **Methodology**

### **Research Area**

*Al-Maabilah* district in Muscat was selected as a case study for this research because it is still under development and it has been attracting both business and residential activities due to its location, size, and the fact that the government has approved plans for mega projects in this district -some of them is already under construction-. This gives the researcher the opportunity to study the different types of land use within the district. Figure 1(a) shows the location and boundaries of *Al-Maabilah* district in Muscat Governorate.

The research area was chosen based on several factors such as: activeness of the area, variation of land use, streets configuration and level of development. Areas with about 70-80% development rate were preferred which were identified by several site visits covered the whole district. These areas were selected because they have the potential to provide better insight into the possible designing scenarios of the new adjacent areas based.

Within Al-Maabilah; two neighbourhoods were selected as shown in Figure 1(b). The number of neighbourhoods selected comes in line with earlier published studies where two to four neighbourhoods were studied to explore the relationship between space syntax measures and different patterns of land use e.g. (Lerman and Omer, 2016), (Lamíquiza & López-Domínguez, 2015) and (Hong-Kyu *et. al.*, 2002).

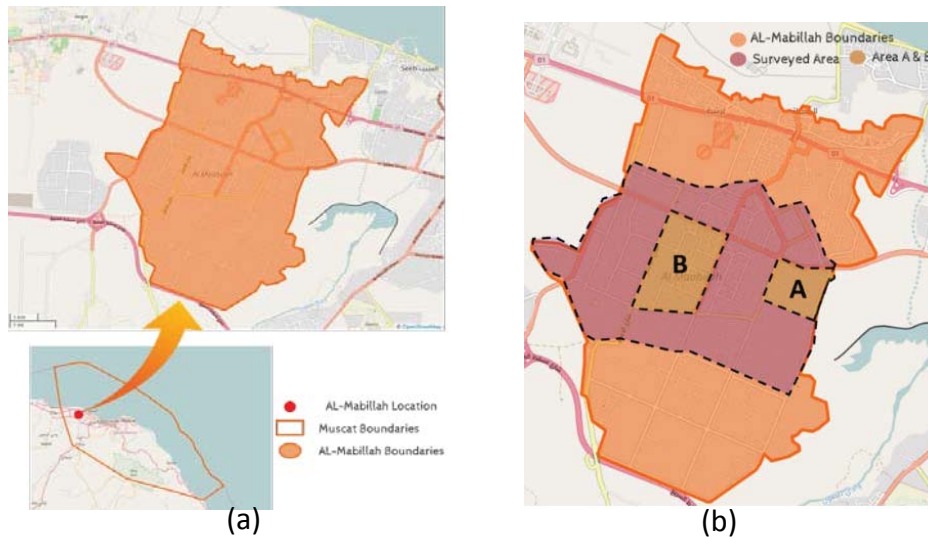


Figure 1: (a) *Al-Maabilah* district within Muscat. (b) The surveyed area and the location of the two neighbourhoods (Source: OpenStreetMap).

The research areas were selected by conducting exhaustive site visits in order to choose appropriate areas with the maximum variation possible in land use. Two neighbourhoods were selected; the first area neighbourhood (A) is located in the east edge of Al-Maabilah and still under construction with medium to high density. While neighbourhood (B) is located in the centre of Al-Maabilah and has higher building density compared to neighbourhood (A). Both areas have similar access from the main road but differ in location as well as notable differences in the grid structure. Neighbourhood (B) has a central area in which the rest of the grid is connected to. The aim of choosing two neighbourhoods in the same area is to explore the existence of a relation between land use and street layout.



Figure 2: The selected case studies; (A) Neighbourhood and (B) Neighbourhood (Source: OpenStreetMap).

Figure 2 provides closer look on each of the research area, while Table 1 summarizes the total number of plots and the ratio between built and unbuilt plots in each neighbourhood.

TABLE 1: The total number of plots, built plots, unbuilt plots and the ratio between built and unbuilt plots.

Neighborhood	Total Number of Plots in the Neighborhood	No. of Built Plots	No. of Empty Plots (Unbuilt)	Built/ Empty
A	800	685	115	5.96
B	2000	1495	505	2.96

## Description of the Variables

### Spatial Variables

Space Syntax Theory and its associated axial line methodology was used to analyse the spatial configuration of the street network of the selected case studies. In spite of the fact that the theory's first focus was on patterns of pedestrian movements, its use has been extended widely to cover many field related to planning and urban design such as modelling of urban traffic, and estimating the potential of retail development and land use distribution (Ratti, 2004). It is based on the assumption that the spatial relationships between spaces (i.e. streets in the city) is a major factor that shapes people's behaviour in spaces (Hillier, 1996). This includes activities such as walking, driving, interacting and retail activity distribution. The use of Space Syntax was extended later to include not only behaviour but also perception and preferences, see for example (Alalouch and Aspinall, 2007) and (Alalouch et al., 2009). Space Syntax methodologies quantify the spatial configuration of urban spaces and it has shown to have a strong explanatory power regarding several activities in urban areas such as land use distribution. Hanson and Zako (2005), page 117, pointed out how powerful Space Syntax is when they stated that *"Space syntax techniques for the analysis of spatial layouts were the first to demonstrate, in a numerical way, clear and systematic relations between spatial design and observed functioning across a range of buildings and urban types"*

Calculation of Space Syntax attributes in this study was based on the axial map of each neighbourhood. The axial map of each neighbourhood was generated using DepthMapX software (Varoudis, 2013) in both graphical and numerical formats. The following variables were considered in this study:

1. Global Integration: is a normalized version of the typological distance from any given space to all other spaces in the configuration. It is a representation of depth and shallowness of a spatial system where highly integrated areas are shown to attract movements and activities (Hillier and Hanson, 1984).
2. Control: is a local measure that measures the amount of choice a space presents to its neighbours as a possible first step in a journey (Alalouch, 2009).
3. Choice: is the extent to which a space can be a part of the shortest route to a destination (Hillier et.al, 1987).
4. Normalised Least Angle Choice (NACH): is a normalised version of the Choice attribute that allows comparisons between spatial configurations of different sizes. It indicates the extent to which an urban area is grid or organic structure (Hillier et. al, 2012). This measure is relatively new in Space Syntax literature.

Integration and Control has been linked to several aspects of people's behaviour and perception in space, see for example (Peatross and Peponis, 1995), (Hillier *et al.*, 1993), (Alalouch and Aspinall, 2007) and (Abbasi *et al.*, 2016); as well as to land use density and price, see for example (Kim and Jun, 2013). Whereas Choice has been linked to land price



(Lee and Kim. 2009). The Normalised Least Angular Choice is seen as a more accurate indicator of urban movement (Andrade and Chronis, 2016). However, little is known about its role in land use distribution.

### *Land use Variables*

This study examines the spatial configuration at the level of streets. Hence, only functional properties that can be applied to a street segment and are of interest to this research, were considered. The following three variables were chosen for the analysis: (1) Residential, (2) Commercial, and (3) Mix-use. These variables were calculated based on an actual field survey of all street segments in the research areas. Each plot on every street segment was assigned with its land-use through the exhaustive field survey.

### *Data Collection*

The plans of the selected areas were acquired from Muscat Municipality in DWG format. These plans were updated by conducting site visits and checking the updated google earth maps, OpenStreetMap and OMANPIXEL maps to match the existing streets with the current plot layout.

### *Land use Mapping*

Land use data was collected from site visits, by first naming and defining the main roads and secondary roads, and then identifying the land uses of each plot surrounding each road in order to produce land use maps for both neighbourhoods. Figure 3 shows the land use maps for neighbourhood (A) and (B). An initial examination of these land use maps provides a brief and preliminary insight into how the street configurations affect the distribution of the land use, the dominant land use in the area, and how different types of land use relate to each other. It can be noticed that the religious buildings are always connected to residential areas, whereas the commercial and mix-use buildings are located at the corners and edges of the neighbourhoods surrounding residential buildings.

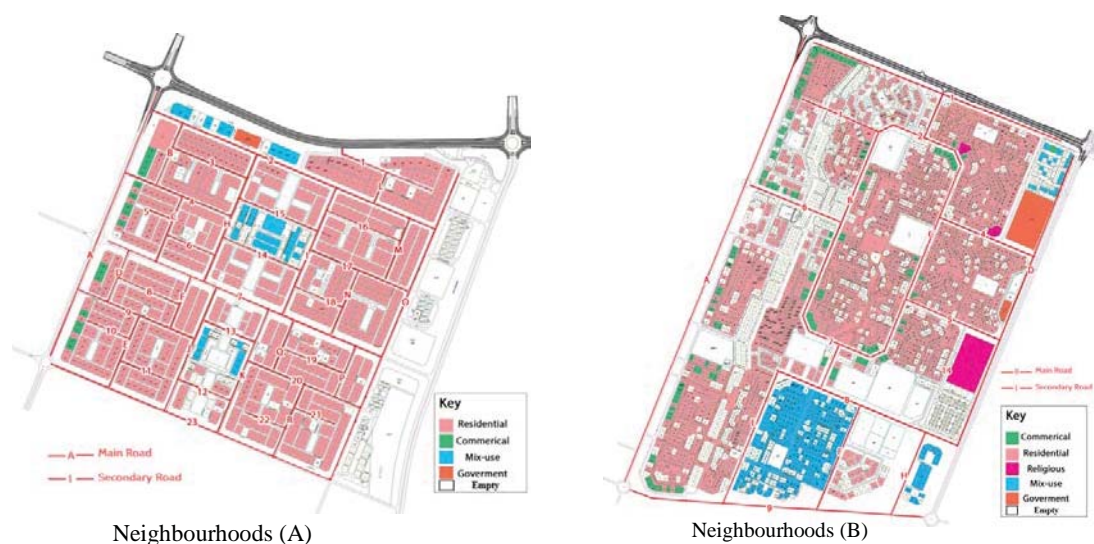


Figure 3: Land use maps of the two neighbourhoods.

### ***Axial Line Analysis***

The Axial lines method was used in this study because it is more appropriate for urban scale projects, which was used in many earlier studies (Lerman and Omer, 2016), and (Hillier and Hanson, 1984). In addition, streets are narrow and long, so axial lines are more appropriate than convex graph and Visibility Graph Analysis in describing this types of spaces. Axil lines are defined as the minimum set of straight lines covering the urban street network. They represent the actual accessible line of sight of each street, which in turn represents the perception of people of the built environment. The main and secondary streets of each selected area were considered in the analysis, making 80%-90% of the selected neighbourhoods, with the minor streets stemming out of the secondary streets being neglected as they have a minor influence on the scope of this research. Streets then were converted to convex spaces in order to produce a convex map. DepthMapX software was used to generate the axial maps of the two neighbourhoods. Neighbourhood (A) consisted of 94 axial lines, whereas Neighbourhood (B) consisted of 394 axial lines.

### ***Correlation Analysis***

Correlation refers to the strength of a relationship between two variables. A strong, or high, correlation means that two or more variables have a strong relationship with each other, while a weak or low correlation means that the variables are hardly related. Correlation coefficients can range from -1.00 to +1.00. The value of -1.00 represents a perfect negative correlation, which means that as the value of one variable increases, the other decreases. While a value of +1.00 represents a perfect positive relationship. A value of zero means that there is no relationship between the variables being tested (Field, 2005). Correlation analysis between spatial variables and land use variable was conducted using SPSS software. In order to conduct correlation analysis using this software, (i) the axial line's numerical data from DepthMapX for both neighbourhoods were exported to CVS file, (ii) then land use data were produced in the same CVS file based on the data from the field trips. The resulted file was then inserted into SPSS for statistical analysis.

## **Results**

### ***Land use Distribution***

There were differences in the urban street configurations between the two neighbourhoods. Neighbourhood (A) is considerably smaller with clear grid lines that run across the area. Moreover, this neighbourhood's street network is symmetrical along the vertical axis of the area. Neighbourhood (B) is around 40% larger than neighbourhood (A), with a weaker grid layout and unclear roads that cut through multiple zones of the area compared to the straight and clear grid of neighbourhood A. The urban density of the built area in the two neighbourhoods is around of 89% in neighbourhood (A) and 84% in neighbourhood (B). The land use mapping shows initially that most of the commercial plots are located on the outer streets of the areas with easy accessibility. For the mixed land use, the plots are located in the middle of the area in neighbourhood (A), but on the outer streets of neighbourhood (B). In the crowded areas between the houses where the population is high, the number of mixed-use buildings is higher. This suggests that there is a difference in the spatial configuration between the two areas, in terms of their local spatial structure as well as their global context.

### Axial Line Analysis

As described earlier, axial lines maps were produced for each neighbourhood using DepthMapX. The differences in the urban street configuration between neighbourhood (A) and (B) is shown in Figures 4 and 5 respectively, which illustrate the axial maps for three spatial attributes considered in this study: Integration, Control and NACH. A visual examination of the axial maps shows that the highest integration values in neighbourhood (A) is located at the central roads, whereas in neighbourhood (B) at the boundaries of the site. The central street in neighbourhood (A) has also the highest Control and NACH values unlike neighbourhood (B). When comparing these results to the land use distribution it can be noticed that most of the mixed land use is located in highly integrated streets.

In order to explore the difference between the spatial structures of the two neighbourhoods as a whole, the values of the spatial attributes of all streets in each neighbourhood were averaged. Table 2 shows that neighbourhood (A) has higher Integration value and lower Control value than neighbourhood (B). This indicates that Neighbourhood (A) is more accessible but provides slightly less visual control when compared to neighbourhood (B). However, the difference in Control value is not significant (neighbourhood A=0.96, neighbourhood B=1.02).

TABLE 2: Descriptive statistics of the spatial attributes values for the two neighbourhoods.

		Integration	Control	Choice	NACH
Neighborhood A (N=77)	Mean	1.54	0.96	276.26	0.6
	Max	3.09	2.79	2170	0.47
	Min	0.87	0.17	0	0
	Std. deviation	0.45	0.64	445.32	0.95
Neighborhood B (N=336)	Mean	1.1	1.02	2363.7	0.031
	Max	1.74	6.3	36784	0.48
	Min	-1	0.13	0	0
	Std. deviation	0.29	0.6	4723.06	0.62

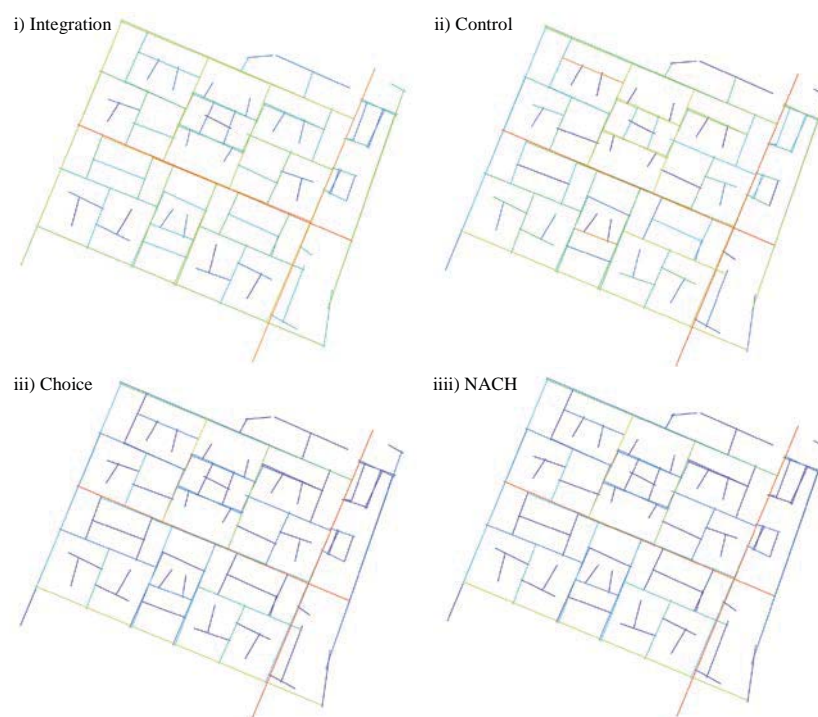


Figure 4: The axial map analysis of neighbourhood (A). Scale: blue (lower values) to red (higher values).



Figure 5: The axial map analysis of neighbourhood (B). Scale: blue (lower values) to red (higher values).

The NACH attribute for neighbourhood (A) is higher than neighbourhood (B), which indicates that the neighbourhood (A) has a more formal grid structure than neighbourhood (B). In fact, this can be observed in the planes of the neighbourhood shown in Figures 2. The NACH provides a numerical description of the differences between the two neighbourhoods in terms of having a grid or organic structure.

The table shows also that the Standard Deviation of the choice attribute in both neighbourhood is unexpectedly high. An investigation of the histogram of this variable reveals that the sample is highly skewed toward the lower values as shown in Figure 6. Accordingly, the choice variable was excluded from the following analysis.

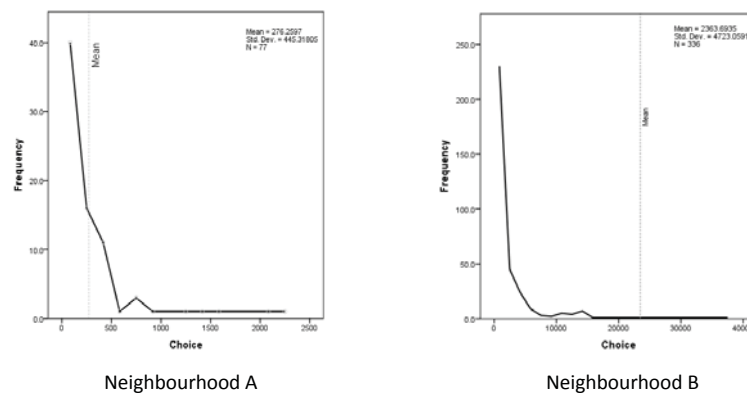


Figure 6. Histograms of the Choice variable in the two neighbourhoods showing the highly skewed sample.

### ***The Relationship between Land use and the Spatial Attributes***

Prior to conducting any statistical test, the normality of the distribution of the variables (Residential, Commercial, Mix-use, Integration, Control, and NACH) were checked using One-sample Komogorov-Smirnov test (K-S). This step was necessary to help in selecting the appropriate correlation coefficient that best describes the relationships between the variables in the data set. The results of the K-S test, shown in Table 3, indicate that none of the distributions of the variables is normally distributed. In such a case, Field (2005) recommended the use of the non-parametric Spearman Correlation Coefficient.

TABLE 3: Test of normality.

	Neighborhood A (df=77)						Neighborhood B (df=336)					
	Residential	Commercial	Mix-use	Integration	Control	NACH	Residential	Commercial	Mix-use	Integration	Control	NACH
K-S statistic	.162	.529	.471	.110	.126	.268	.187	.461	.505	.128	.160	.309
Sig.	.000*	.000*	.000*	.022*	.004*	.000*	.000*	.000*	.000*	.000*	.000*	.000*

\*. Significant values. Note: significant value of K-S test indicates deviation from normality.

Accordingly, the non-parametric Spearman Correlation Coefficient was used to assess the relationships between land-use variables (Residential, Commercial, and Mix-use) and Space Syntax variables (Integration, Control and NACH) in the two neighbourhoods. The results are shown in tables 4.

TABLE 4: The relationship between land use variables and the spatial variables in the two neighbourhoods.

			Residential	Commercial	Mix-use
Neighborhood A (N=77)	Integration	Spearman Coefficient	.469**	.250*	.100
		Sig. (2-tailed)	.000	0.028	.389
	Control	Spearman Coefficient	.396**	-.013	.203
		Sig. (2-tailed)	.000	.911	.077
	NACH	Spearman Coefficient	.545**	.190	.192
		Sig. (2-tailed)	.000	.098	.094
Neighborhood B (N=336)	Integration	Spearman Coefficient	-.066	-.013	.146**
		Sig. (2-tailed)	.229	.818	.007
	Control	Spearman Coefficient	-.069	.044	.110*
		Sig. (2-tailed)	.208	.424	.043
	NACH	Spearman Coefficient	-.113	0.16	.104
		Sig. (2-tailed)	0.06	.765	.057

\*\*. Correlation is significant at the 0.01 level, \*. Correlation is significant at the 0.05 level.

The residential land use variable were found to positively and moderately correlate with the three spatial variables in neighbourhood (A) (Integration:  $r=0.469$ ,  $p<0.01$ , Control:  $r=0.396$ ,  $p<0.01$ , NACH:  $r=0.545$ ,  $p<0.01$ ) with NACH being the strongest indicator of the distribution of the residential land use flowed by Integration then Control. Contrary, no correlation were found between this variable and any of the spatial variables in neighbourhood (B). The commercial land use variable correlated positively with Integration in neighbourhood (A) only. Although this correlation is statically significant, it is notably



weak ( $r=0.250$ ,  $p>0.05$ ) and hence cannot be considered. Similarly, the Mix-use variable showed a weak and neglectable correlation with Integration ( $r=0.146$ ,  $p<0.01$ ) and Control ( $r=0.110$ ,  $p<0.05$ ) in neighbourhood (B).

In summary, the results of the Spearman correlation showed that the distribution of the residential land use in neighbourhood (A) increases with the increase in the three spatial attributes. NACH were found to correlate the best with the Residential land use followed by Integration. In neighbourhood (B), no correlations were found between the residential land use and Integration. In addition, the Commercial and Mix-use land uses did not correlate with any of the spatial attributes in the two neighbourhoods. In fact, the finding with regard to Integration in neighbourhood (A) is not surprising. Several studies has reported correlation between Integration and land use distribution as explained earlier. However, and to the authors' best knowledge, the role of NACH in the distribution of land uses has not been reported earlier in the literature.

The remaining question is then why such a relationship does not exist in neighbourhood (B)? In other words, what is the effect of the neighbourhood as whole on the relationship between Space Syntax attributes and land use distribution?

### ***The Effect of the Neighbourhood***

The first assumption to test is whether the degree to which a neighbourhood is a formal grid effects the relationship between Integration and the Residential land use. This can be measured by the value of NACH. Higher NACH value indicates more grid structure (Hillier et. al, 2012). A close exanimation of Table 2 reveals that the NACH average value of neighbourhood (B) is notably lower than that of the neighbourhood (A). This suggest that the street network of neighbourhood (B) is less formal grid and has more organic structure when compared to neighbourhood (A). In order to test this observation statically, a partial correlation analysis was carried out between Integration and Residential land use with the NACH being controlled for.

The results show that there was moderate, positive partial correlation between Integration and Residential, whilst controlling for NACH, which was statistically significant ( $r(407)=.277$ ,  $p<0.01$ ). However, Zero-order correlation showed that there was a statistically, moderate, positive correlations between the two variables ( $r(408)=.437$ ,  $p<0.01$ ) indicating NACH has very little influence in controlling for the relationship between Integration and Residential land use. The relationship between Integration and NACH for the two neighbourhoods is shown in Figure 7.

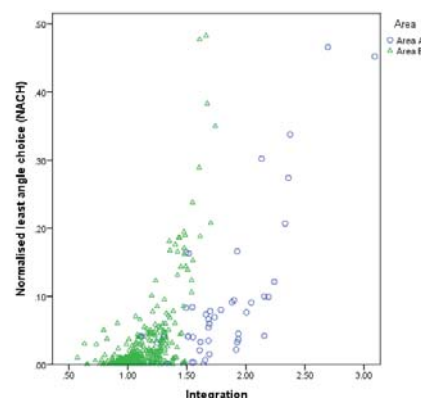


Figure 7. The relationship between Integration and NACH in the two neighbourhoods.

The next assumption to test is whether the “Intelligibility” of the spatial configuration effects the relationship between the spatial attributes and land use distribution. Intelligibility is a measure of the extent to which the local properties of a spatial configuration indicate its global one. It is measured by the degree of correlation between Connectivity (as a local measure) and Integration (as a global measure). Stronger correlation between these two spatial attributes means higher level of intelligibility. The importance of this measure is that several studies reported higher level of correlation between Space Syntax measures and different behaviour in highly intelligible configurations, see for example (Hillier, 1996) and (Kim, 2001). In order to explore the Intelligibility degree of the two neighbourhoods, a scatter plot between Connectivity and Integration were produced for each neighbourhood separately. Figure 8 shows that there is a relationship between Connectivity and Integration in neighbourhood (A) but not in neighbourhood (B).

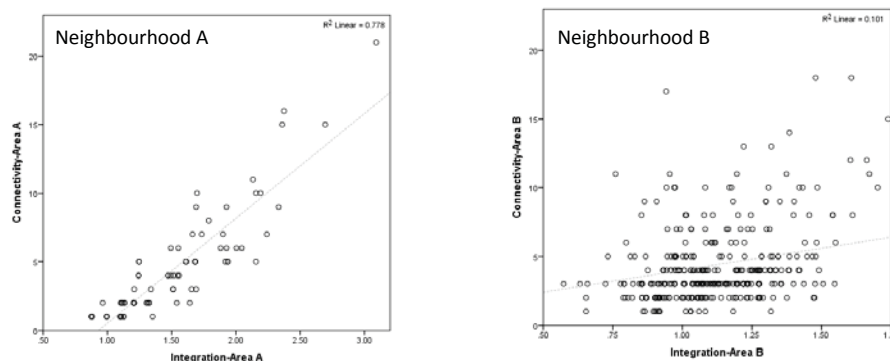


Figure 8. Intelligibility of the two neighbourhoods.

In addition, spearman correlations coefficient confirmed that there is a significant positive correlations between the two variables in neighbourhood (A) ( $r(77)=.890$ ,  $p<0.001$ ); whereas in neighbourhood (B) the relationship is much less strong ( $r(336)=0.240$ ,  $p<0.001$ ). This indicates that neighbourhood (A) is significantly more intelligible when compared to neighbourhood (B). These results suggest that the effect of the spatial arrangement on lands use distribution -in this case the Residential land use- is more severe in highly intelligible spatial configurations in Muscat. Hence, Space Syntax attributes can be used to predict land uses in newly developed areas in Muscat only if it was designed in a way that its local spatial structure indicates its global one.

## Discussion and Conclusions

This paper explored the relationship between land use distribution and Space Syntax measures in the newly developed areas in Muscat, Oman. Two areas in *Al-Maabilah* district in Muscat were selected as case studies. Land use maps were produced based on exhaustive field trips, whereas the spatial attributes were calculated using axial map analysis of the areas based on Space Syntax methodology. Three land use variables that are of interest to this study –i.e. Residential, Commercial, and Mix-use– were correlated with four spatial attributes –i.e. Integration, Control, Choice, Normalized Least Angle Choice (NACH) –. These spatial attributes are linked in the literature to aspects of the built environment that are relevant to this study.

The results of the correlation analysis carried out between the two sets of variables revealed the existence of relationships between land use distribution and some spatial attributes in the selected case studies. In particular, the Residential land use were found to

positively correlate with three out of the four spatial attributes considered in this study; with NACH showing the strongest correlation followed by Integration. While the role of Integration in land use distribution and land value has been reported in the literature, the relation between the Residential land use and NACH is exclusive to this study.

These relationships were found in the highly intelligible area only, indicating that the use of spatial attributes –i.e. NACH and Integration– in predicting the distribution of the residential land use is only possible in areas where the local spatial structure provides strong indication of its global spatial structure.

To sum up, the findings of this study revealed that the distribution of the Residential land use is significantly influenced by the spatial attributes in highly intelligible spatial configurations; with NACH being the best predictor of the distribution of the Residential land use followed by Integration. Although this study considered a certain spectrum of the spatial attributes of Space Syntax, it provides evidences on how space design effects certain human behaviour and economic activities such as land use distribution. Further work should expand the analysis to include different countries in the region and further explore the role of NACH in this context.

These findings might provide urban design guidelines for the local authority in Oman. Such systematic relationships between the plan configuration and land use distribution provide a context within which design proposals can be assessed to achieve a desired design goal (increase or decrease a certain land use in an area); by reinforcing the relevant spatial properties that are inherited in the design itself. In particular, the link between the spatial intelligibility of an area and the ability of the spatial attribute to predict the residential land use is of great benefit in the context of assessing urban design proposal of new developments in Muscat.

This paper contribute to the Space Syntax literature and land use distribution studies by providing a further evidence of the role of Integration in the distribution of land uses; as well as providing a new insight into the importance of NACH as a measure to predict the distribution of the residential land use in the newly developed areas. Studies concerning NACH are scarce and little is known about the role of this spatial attribute and hence the originality of this work. Equally importantly this study has showed that what matters in terms of the ability of the spatial attribute to predict the residential activities in the newly developed areas is the level of the spatial Intelligibility of the area and not how grid or organic the spatial structure is.

## References

- Abbasi, A., Alalouch, C. & Bramley, G., (2016). Open Space Quality in Deprived Urban Areas: User Perspective and Use Pattern. *Procedia - Social and Behavioral Sciences*, Volume 216, pp. 194-205. doi:10.1016/j.sbspro.2015.12.028
- Abdulfatah, N. (2015). The potential of urban expansion in the sultanate of Oman (in Arabic). *Alwatan*. Retrieved from <http://alwatan.com/details/76773> (Accessed: 11 October 2016).
- Alalouch, C. & Aspinall, P., (2007). Spatial attributes of hospital multi-bed wards and preferences for privacy. *Facilities*, 25(9/10). 18.
- Alalouch, C., (2009). Hospital Ward Design: Implications for Space and Privacy. Ph.D. Thesis, Heriot Watt University, Edinburgh.
- Alalouch, C., Aspinall, P., & Smith, H., (2009). On locational preferences for privacy in hospital wards. *Facilities*, 27(3/4), 88–106.
- Alalouch, C., Saleh M. S., Al-Saadi, S., (2016). Energy-Efficient House in the GCC Region. *Procedia - Social and Behavioral Sciences*, Volume 216, Issue , P. 736-743, DOI: <https://doi.org/10.1016/j.sbspro.2015.12.071>

- Alkamali, N., Alhadharami, N., Alalouch, C., (2017). Muscat City Expansion and Accessibility to the Historical Core: Space Syntax Analysis. *Energy Procedia*, Volume 115, p. 480–486, DOI: <https://doi.org/10.1016/j.egypro.2017.05.044>
- Andrade, R. and Chronis, A., (2016). Self-Reported Positioning within Spatial Configurations: Combining Big Data and Space Syntax Analysis for Urban Mobility Research. *Proceeding of Simulation in Architecture and Urban Design conference*, London, 16-18 May 2016.
- Desyllas, J., (2000). The relationship between urban street configuration and office rent patterns in Berlin. *Bartlett School of Graduate Studies*. London, University College London.
- Field, A., (2005). *Discovering Statistics using SPSS for Windows*. Second Edition. London, SAGE Publication.
- Hanson, J. & Zako, R., (2005). Configuration and Design in Caring Environments: syntax and quality of life in a sample of residential care homes for older people. *5th International Space Syntax Symposium*, Delft.
- Hillier, B. & Hanson, J. (1984), *The Social Logic of Space*, Cambridge University Press: Cambridge.
- Hillier, B., (1996). *Space is the machine: A configuration theory of architecture*. Cambridge, UK, Cambridge University Press.
- Hillier, B., Burdett, R., Peponis, J., Penn, A., (1987), *Creating Life: Or, Does Architecture Determine Anything? Architecture et Comportment/Architecture and Behavior*, 3 (3) 233 - 250.
- Hillier, B., Penn, A., Hanson, J., Grajewski, T. and Xu, J., (1993). "Natural movement: or, configuration and attraction in urban pedestrian movement." *Environment and Planning B: Planning and Design*, 20, p. 29 - 66.
- Hillier, B., Yang, T., and Turner, A., (2012). Normalizing least angle choice in Depthmap and how it opens up new perspectives on the global and local analysis of city space. *The Journal of Space Syntax*, 3 (2), 155-193.
- Hong-Kyu, K., & Dong, S. W., (2002). An analysis of the relationship between land use density of office buildings and urban street configuration: Case studies of two areas in Seoul by space syntax analysis. *Cities*, Vol.19, No .6, pp. 409-418.
- Kazem, H. A., (2011). Renewable energy in Oman: Status and future prospects. *Renewable and Sustainable Energy Reviews*, 15(8), p. 3465–3469.
- Kim, H., Y. and Jun, C., M., (2013). Spatial Analysis of the Relationship between Space Syntax and Land Use Density. *Proceedings of the 9<sup>th</sup> International Space Syntax Symposium*, Seoul: Sejong University, 31st October 2013.
- Kim, Y. O., (2001). The role of spatial configuration in spatial cognition. *3<sup>rd</sup> Space Syntax Symposium*, Atlanta.
- Koning, R. E., Van Nes, A., Ye, Y., & Roald, H. (2017). Strategies for Integrated Densification with Urban Qualities: Combining Space Syntax with building density, land usage, public transport and property rights in Bergen city. *Proceedings of the 11th Space Syntax Symposium*, (pp. 56.1-56.17). Lisbon.
- Lamiquiza, P. & López-Domínguez, J., (2015). Effects of built environment on walking at the neighborhood scale. A new role for street networks by modelling their configurational accessibility. *Transportation Research Part A: Policy and Practice*, Volume: 72, p. 148-163.
- Lee, I. H. & Kim, Y. O., (2009). The Effect of Spatial Configuration and Land Use Pattern on Land Price Formation. *Proceedings of the 7<sup>th</sup> International Space Syntax Symposium*, Stockholm, 8-11 June 2009.
- Lerman, Y. & Omer, I., (2016). Urban area types and spatial distribution of pedestrians: Lessons from Tel Aviv. *Cities*, pp. 11-23.
- Min, K. M., Moon, J. M., and Kim, Y. O., (2007). The Effect of Spatial Configuration on Land Use and Land Value in Seoul. *6<sup>th</sup> International Space Syntax Symposium*, Istanbul.
- Peatross, D., and Peponis, J., (1995). "Space education and socialization." *Journal of Architectural and Planning Research*, 12(4), p. 366 - 385.
- Ratti, C., (2004). "Space syntax: some inconsistencies." *Environment and Planning B: Planning and Design*, 31, p. 487 - 499.
- Salah, M.S. & Alalouch, C., (2015). Towards sustainable construction in Oman: Challenges & Opportunities. *Procedia Engineering*, Volume 118, Issue C, p. 178-185, DOI: 10.1016/j.proeng.2015.08.416
- Seok H.J. & Lee M. H., (2008). Analyses of CBD Land-Use Characteristics Based on the Space Syntax. *Architectural institute of Korea* v.24 n.5: 211-230
- Varoudis T., (2013). *DepthmapX Multi-Platform Spatial Network Analysis Software*, Version 0.30 Open Source, <http://varoudis.github.io/depthmapX/>. As of 20 September 2016.
- Ye Y. & Nes, A., (2013). Measuring urban maturation processes in Dutch and Chinese new towns: Combining street network configuration with building density and degree of land use diversification through GIS. *The Journal of Space Syntax*, Vol.4, No .1, pp. 18-37.

# Towards Sustainable Prosperity for Informal Settlements - Al Max, Alexandria and Fes El Bali, Fes as cases study

Yasmeen Elsemary<sup>1</sup>

## Abstract:

Egypt as one of the developing countries is in a great suffer from the dense informal settlements which almost in the last few decades extended dangerously to the settlements closer, influencing negatively, resulting deterioration and service lacking.

In general the informal settlements known as slum areas are considered as solutions to the housing problems in many countries by providing the inhabitants self-housing, on the contrary they hold too many negative attributes such as Urban & infrastructure deterioration, social ignorance, cultural problems, lack of educational & health services, unawareness, emergency accessibility lacking , disappearance of community urban spaces, disappearance of public and recreational spaces, lack of transport and communications, lack of social prosperity, low quality of public facilities, besides creating housing units faraway from building construction code and regulations, in addition to major construction problems, all these considered as the basis of the quality of urban life.

Thus the need for solution was necessary without the intention for demolition nor destroying these settlements; yet the solution would go for a sustainable progressed approach to upgrade and enhance these settlements reaching quality of life attributes for the inhabitants nowadays and in the future towards both; the informal settlements and the neighbourhoods nearby.

This paper aims at pursuit the sustainable agenda, determining the datum of accepted well-being community through determining a group of indicators and principles believed to be the sustainable base approach reaching quality of life to substitute the informal settlements to more reasonable rational settings, targeting upgrading the whole city as well, via striving experimenting national and international case-studies to reach relevant assessment.

**Keywords:** livability, quality of life, social sustainability, informal settlements

## Introduction

Recognizing that environmental and social needs are unlikely to be met if human needs are ignored, and while the requirements and needs of users vary from place to place in the same city, to achieve this, planners are interested in improving the quality of life for users through the quality of services such as quality of buildings, public and recreational places, transport and public facilities, and attention to the needs of people with special needs considered as the basis of the quality of urban life. Relating such broad concerns to that of sustainable urban design, human needs encompass many of the perceptual and social needs discussed in this, including local access to comfortable environments that are visually attractive; that allow safe human contact, and ease of movement; which are socially mixed through their design and the disposition of uses are available to all. This paper introduces new and old neighbourhoods of Al Max-Alexandria, in Egypt and Fes El Bali-Fes, in Morocco as the study sites to investigate the sustainable urban design and sustainable community in all senses.

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## METHODOLOGY

This research attempts to answer the following key question: to what extent the informal settlements in Arab Cities could reach the social quality of life trends in order to fulfil human needs. To answer the research question, the research methodology will rely on:

- Review of related literature on the concept of social sustainable development and quality of life of cities ending up with an identification of social sustainability principles that influence the emergence of social sustainable prosperity trends in informal settlements.

- Documentary analysis of social sustainability trends in the region in order to collect social sustainability indicators needed in rehabilitation of informal settlements.

## LITERATURE REVIEW

Socio-economic sustainability is to have a vibrant and healthy community. This can be achieved by factual forecasts for housing needs, for both present and future generation. It should have adequate local services that fulfil and support its health, social, and cultural needs (Woodcraft, 2012). It should preserve open spaces with a good community oriented human environment in diversity with compact and mixed land use, with the decrease of energy use, waste and pollution as well. It should enhance the feeling of well-being by having sustainable transportation, green areas, and solar and other renewable forms of energy, this is done by understanding what people need from a place (Palich & Edmonds, 2013). Social sustainability deals with people's quality of life; it combines the design of the physical environment with emphasis on the way people live, and use the space to function and relate to each other (Nil, 2014).

People are not passive, however, and influence and change the environment as it influences and changes them. It is thus, a continuous two-way process in which people create and modify spaces while at the same time being influenced in various ways by those spaces (Carmona et al, 2010). while understanding the relationship between people ('society') and their environment ('space') is an essential topic for urban designers to reach and discover the best shaping of the built environment; the pyramid of human needs is thus composed, see Figure (1), It includes; physiological needs (for warmth and comfort), safety and security needs (to feel safe from harm), Affiliation needs (to belong to a community, for example), Esteem needs (to feel valued by others); and self-actualization (for artistic expression and fulfilment) (Carmona et al, 2010).

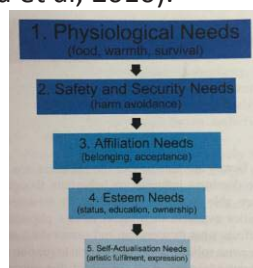


Figure 1. A diagram illustrates the pyramid of human needs.

Source: (Maslow 1968 in Carmona et al, 2010)

### Research Problem: The phenomenon of Informality: Slum areas and informal settlements

The informal housing is an active sector in the Egyptian local economy. According to statistics, it has been able for decades to provide a continuous supply for affordable housing units serving the limited income citizens, more than what the government with all its resources could provide. The informal housing units are under higher demand than the formal ones, which are despite being generated in large quantities; failed to increase the

population of its beneficiaries. This is not restricted to Greater Cairo Region only. Yet the informal housing between 2011 & 2014 has provided and delivered almost 6.5 million housing unit; 3 times more than what was planned by the government in the same period and 43 times what was actually provided for low income groups (UN –Habitat, 2016).

To summarize the RESEARCH PROBLEM:

Since it has been clarified through the literature review; that the ('society') and ('culture') determined as the two pillars of the social sustainability, and since people ('society') are able to create effective environments rather than potential environments designed by the urban designers, and thus live in their own prosper sustainable urban form, the question is why then these informal settlements that are hypothetically owe effective environments, still are not reaching prosperity and social sustainability?

### Research Hypothesis:

Activating the effective environments people create in their urban forms rather than dealing with the potential environments set by the architects and urban designers, will lead to prosperity measurements and sustainable urban settings.

### Quality of Life: Principles and Approaches

Quality of life experienced by citizens is tied to their ability to access infrastructure (transportation, communication, water, and sanitation); food; clean air; affordable housing; meaningful employment; and green spaces, as well as the access to participate in decision-making to meet their needs (Yeun & Giok, 2009) & (Carmona et al, 2016).

Quality of Life has become a global necessity for health, economic and social survival in agglomerations everywhere. In the Egyptian context, owning a flat for lower income group households is a big target, yet they expect more satisfied conditions in the residential units, which reflect their lifestyle that they had aspired. Their degree of satisfaction is strongly linked to the feeling of security, safety, territoriality, and aesthetic values. Despite the Government's several criteria to improve urban residential areas including green areas, proxemics, yet limitation of violations, but at times they fall in shortage with measurements that are critical in determining the desired livability (Mullins, 2017).

What is more, in every country, everywhere, the streets are the place where public life is lived every day. From Algiers to Zurich, streets are filled with people doing everyday things like chatting with their neighbours, hanging laundry, watering flowers, buying food, and socializing (Moor & Rowland, 2006). If we are to rethink the idea of the street (Barkley et al, 2017), we would need to find a way to ensure this vitality of public life has space, in all its forms, and in all its public-ness, see Figure (2).



Figure 2. livable public spaces created by simple ideas in Athens, Greece and London, UK.

Source: the Author, 2016 & 2017

When drawing a street on a plan, you start with a centreline and offset it on two sides. It is quite literally a line connecting two places with a certain width, this width is almost always determined by an engineer who is trying to match an algorithm for how many lanes

are needed for the cars that will drive down this street, and how many utilities will need to comfortably fit here, instead, we should think about streets and all their various uses as places for gathering, finding our way, living more healthfully, with nature, and with each other (Carmona et al, 2010) & (Carmona et al, 2016). Adding, while designers can manipulate functional cues to increase the probability of (more) respectful behaviour in public spaces, what really can be achieved through design is inevitably limited, see Figure (3) & (4), many urban design practitioners, nonetheless, remain optimistic about the probability of particular behaviours in certain environments and advocate good design as a means to achieve certain desirable outcomes, surprisingly users always have additions.



Figure 3. Peter's Hill next to Millennium Bridge, London, UK; where the effective environment created by people leads to putting cushions on the steps, and then putting stones over them in the windy days as a tool for fixation. Source: the Author, 2017



Figure 4. Covent Garden, London, UK; where the effective environment created by people 'society' leads to street entertainment & place theming, representing a successful attempt to build a sustainable community in all senses. Source: the Author, 2017

### ***Towards social sustainability/livability***

It is always expected by home buyers that the residential units they are willing to buy should reflect their identities and their real needs such as; if houses have front porches, then residents will be more neighbourly, and in time will form communities, moreover if the residential roofs are available for usage, this will increase the bonds between residents in the same building, Yet at times they fall on spaces discouraging all these behaviours, but only afford the minimum well-being and basic needs determining the desired livability like a place to live, water supply, sanitation and major roads, surprisingly in the recent years residents have a different point of view, see Figure (5).



Figure 5. Al Max district, the choice of staying in their homes on both sides of the canal other than moving to the new high rise buildings behind submitted by the governorate as shown in the photo; clarifies desired livability. Source: the Author, 2016

### ***Livability key dimensions***

The concept of livability is simple: it assesses which locations around the world provide the best or the worst living conditions. Assessing livability has a broad range of uses, from benchmarking perceptions of development levels to assigning a hardship allowance as part of expatriate relocation packages.

In Livability report 2017; every city is assigned a rating of relative comfort for over 30 qualitative and quantitative factors across five broad categories: stability; healthcare; culture and environment; education; and infrastructure. Each factor in a city is rated as acceptable, tolerable, uncomfortable, undesirable or intolerable. For qualitative indicators, a rating is awarded based on the judgment of in-house analysts and in-city contributors. For quantitative indicators, a rating is calculated based on the relative performance of a number of external data points (the EIU, 2017).

The following principles are suggested as basic to the livable city (Yeun & Giok, 2009).

- a public realm offers activities, that bring all residents together.
- is not dominated by fear.
- offers a place for social learning and socialization for children and young people.
- must meet many functions; economic, social and cultural.
- beauty, and meaning of the physical environment must have high priority.
- wisdom and knowledge of all residents are appreciated and used. People are not intimidated by experts, whether architects or planners, but show a sense of caution and distrust of those who make decisions about their lives.

A livable city satisfies the needs of the present inhabitants without reducing the capacity of the future generation to satisfy their needs (Taha, 2013). Both social and physical elements must collaborate for the wellbeing and progress of the community and of the individual persons as members of the community. It is a city where common spaces are the centres of social life. Cities built up, as a continuous network from the central areas to the distant settlements, where pedestrian paths and bicycle paths don't bind together in all the sites of social quality and of the community life (Carmona et al, 2016).

These definitions and other uses of the term suggest that livability has a number of key dimensions; importantly most definitions align livability with local community wellbeing, concerning how people interact with in local environments (Yu, 2017), Yet at least the much defined indicators towards livability in poor areas are determined as: accessibility of public places (schools, health care centres, and parks), availability of open spaces and environmental quality (cleanliness, rainwater management and safety) see Figure (6).



Figure 6. Tora Neighbourhoods in el Maadi district, Cairo; isolated urban environments lacking livability fundamental principles such as cleanliness of the city, and safety. Source: the Author, 2010

### **RESEARCH APPROACH**

A city representing various facets relating to culture, religion, behaviour etc. of Egyptian society was selected to carry out the research work. Alexandria, the second largest city of Egypt after the capital Cairo, specifically Al Max district was selected for the study. Alexandria is well connected to other cities through rail, roads and air and has been



attracting people from all parts of Egypt. The study was carried out in the city of Alexandria to understand how people perceive livability of residential areas. So it was important to discuss and ask various issues with the whole family members in this district and keen to get opinions of women and children. Interviews and discussions were recorded through voice recorder and later transcribed. Care was taken to ensure that, as far as possible, the sense of participants' comments was not altered. The researcher was involved in the analysis and interpretation of the data in order to maximize the validity and reliability of the results. An iterative process of data interpretation was undertaken to discern the common factors and important aspects, arising from inhabitant's perceptions of livability. The results that emerged from the responses given by participants are likely to be indicative of the attributes which are most important to people in judging livability in an Egyptian context.

On the other hand a city representing various facets relating to culture, religion, behaviour etc. of Moroccan society was selected to carry out the research work as well. Interviews and discussions held with inhabitants in Fes El Bali, Morocco seeking a comparative analysis between two countries targeting social sustainability.

## STUDY CASES

The cases were selected to represent cities from two countries Egypt and Morocco, two districts that managed to enhance quality of urban life through an integral multi approaches strategy, towards better social sustainability. An analytical comparative study is composed, based on qualitative and quantitative methods; the following table (1) shows the defects in every district.

Table 1. The main defects found during data gathering in the two case studies. Source: the Author

ALMAX - ALEXANDRIA, Egypt	Fes El Bali - Fes, MOROCCO
Quality of infrastructure	Emergency accessibility
Safety and security	Quality of public facilities
Quality of local public amenities	Building construction code
Environmental and visual character	Quality of services
Planning, land use housing	Recreational places
	Attention to the needs of people with special needs

### *Al Max district, Alexandria*

Egyptians live on about 7.7% only of Egypt's total land area, the rest is a mere desert; the population of 92 million people (state information service) are concentrated in the main cities, such as Cairo, Alexandria and Giza where the concentration of services, leading to the immigration of citizens from the countryside to those cities, which have a better quality of life and services, causing over-population and stress on resources. The new immigrants usually cannot afford living in the expensive neighbourhoods, preferring to create informal settlements; one of these settlements is Al Max district, in Alexandria. Houses in those areas are usually built at a minimum cost, neglecting most aesthetic, hygienic and environmental aspects, see Figure (7).



Figure 7. Al Max district Houses, Houses at a minimum cost. Source: the Author, 2016



Alexandria is the chief port of Egypt and is located in the north and occupies a T-shaped peninsula and strip of land separating the Mediterranean from Lake Maryout, see Figure (8). It was founded in 331 BC by Alexander the Great and was the capital of Egypt for over 1000 years and its population is about 4.546 million according to the latest statistics. Because of this, Alexandria is the second largest urban governorate in Egypt. This enormous urban growth requires precise detection with good management, prediction and planning.

The New Dekhila Port in the west of the city covers a great area of the land and areas of the sea, moreover a wide area of the desert and the coastal plain has been developed as a new location for urban housing; such as Al Max district, Al Max district is one of Alexandria districts, stated in Al Aamria zone which located west Alexandria. Al Max in Arabic is a word derived from Al Mokoos which means "to excise" or the customs, as this place was known as the customs for the western goods. Al Max has a special nature with a stacking and ordered view of fishermen houses around mouth water coming from Mahmoudia canal which in turn pours in the Mediterranean Sea. The main profession there is fishing using small boats they inherit from generation to generation, while their houses extend at a distance of 1.5 kilometres in a unique architectural pattern taking a stacking hierarchal view on the canal as shown in Figure (9).



Figure 8. Area of study

Source: <http://research.ncl.ac.uk/forum/v5i1/azaz.p>



Figure 9. The popular character shown in fishermen homes in Al Max, spontaneously built without an engineer, known as it is since the seventies, Source: the Author, 2016

### ***Fes el Bali, Morocco***

Fes is a north-eastern Moroccan city often referred to as the country's cultural capital. It's primarily known for its Fes El Bali walled medina, with medieval Marinade architecture, vibrant souks and old-world atmosphere. The medina is home to religious schools such as the 14th-century Bou Inania and Al Attarine; to the extent that it is known as the religious centre of Morocco. Fes is the second largest city of Morocco, after Casablanca, with a population of 1.112 million from a whole population of 35,248,714 million existed in Morocco according to the latest statistics, see Figure (10)

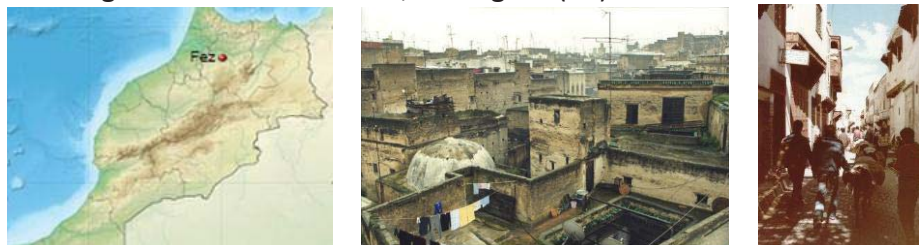


Figure 10. Left photo: Map of Morocco showing area of study; Fes in the north eastern figure. Right and middle photos: show narrow alleyways in an ancient medieval city believed to be the world's largest car-free urban zone. Source: [https://en.wikipedia.org/wiki/World\\_map](https://en.wikipedia.org/wiki/World_map).

Fes was the capital city of modern Morocco until 1925 and is now the capital of the Fes-Meknes administrative region. The city has two old medina quarters, the larger of which is Fes el Bali, see Figure (11). It is listed as a World Heritage Site and is believed to be one of the world's largest urban pedestrian zones (car-free areas). The city has been called the "Mecca of the West" and the "Athens of Africa", a nickname it shares with Cyrene in Libya.



Figure 11. The vibrant souk next to Bou Inania religious school in the left photo, and the leather tanneries where the leather industry takes place in the right photo. Source: the Author, 2017

## DISCUSSION


### ANALYSIS OF RESIDENTS' RESPONSES





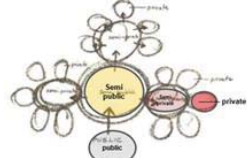
The researcher collected the responses which were developed during different times across the two cities. It has been shown that the residential areas had acquired different problems and strengths during the process of their developments. The researcher asked and interviewed with four hundred residents in these residential areas.





Participants were interviewed individually to have a first-hand understanding of phenomenon and to ensure data integrity. Interviewer was as non-intrusive as possible to allow participants the freedom to present their own meanings of livability. Participants' responses were analysed in terms of their perceptions of satisfaction of the existing livability indicators in Egypt and Morocco, yet their understanding of local livability concerns, and their suggestions for how livability problems should be solved, see Table (2).

Gathering all the previous together; (the pyramid of human needs, the principles that are suggested as basics to the livable city, the defined quantitative and qualitative indicators towards livability in poor areas found by the livability surveys, and the defects found in the two study cases (Al Max and Fes El Bali), the researcher gathered altogether concluding the following table as a measurement for social quality of life indicators after questioning the inhabitants as a trial to analyse the perceived indicators due to them and proposing solutions.

Table 2. Analysing the problem of livability indicators within proposing solutions. Source: the Author

Indicators (major)	Indicators (minor)/ subdivisions	Inhabitants' satisfaction of the existing indicators						livability essential indicators stated by the inhabitants	Proposed solutions for some indicators to be enhanced
		Al Max, Alexandria, Egypt			Fes El Bali, Fes, Morocco				
		v. good	good	poor	v. good	good	poor		
Social Upgrade	Space for public activities and communication		●				●	Socio-Cultural aspects converged in these communities by activities related to music and performance in which require a theatre, may be	 Outdoor theatre

	Space for markets (buying and selling)			●		●	an outdoor one, as well as an organised market including all sorts of goods specialised in the district to be accessed by externals.	 Mixed use Open markets
Aesthetic quality	Aesthetics standards			●	●		<p>Creating a sense of place is a major requirement to gain livability, could be enhanced by several applications, all towards fine views and good details as well as pleasant facades, in Al Max ; inhabitants want to upgrade their facades, yet there is no budget for this, they prefer to upgrade their boats instead to help to increase their profession, so they go for painting on facades expressing their identities, using local materials. Yet in Fes el Bali, facades are much better, interesting, old and authentic, but lack conservation in some slots, while the overall context lack organization.</p>	 15 principles of Christopher Alexander towards aesthetics
	Fine views			●		●		 Community art in Al Max represented in graffiti
	owing a sense of place		●		●			Awareness' raising in these communities could be the only solution to let them upgrade their sense of aesthetics, even in a very simple way such as spotting the light on few easy principles to gain beauty, as well as focusing on local materials used in graffiti and boats' painting.
	Beautiful facades			●		●		
Quality of infrastructure	Availability of services Maintenance			●		●	<p>The minimum need of any community is to get adequate and quality water supply and 24 hours supply of electricity.</p> <p>Fes residents are upset with this indicator: due to narrow alleyways and thick walls, lighting at night is not good.</p>	<p>Suggestions go for establishing new electrical boxes as suppliers in different nodes selected by the inhabitants themselves.</p> 
Safety and Security	Feel safe at home		●			●	<p>Safety and security are viewed as a primary requirement for living. Whether Al Max or Fes El Bali, both encompass activities such as fishing, leather, carpets, copper and pottery which invite customers and therefore nuisance, thus they don't feel secure. Participants in Fes el Bali registered their need for walking comfortably and fearlessly in streets; moreover they seek strategies for crime and disorderly behaviour avoidance especially because vagrants pretended to be customers are many.</p>	 Schematic sketches illustrating Hierarchy of defensible space from public to private showing surveillance.
	Disorderly behaviour avoidance			●		●		
	Social acceptance of residential area	●				●		
	Feel safe in street		●			●		

Quality of Local Public Amenities	Location attributes		●				●	Emergency accessibility is very difficult in Fes because of streets' width, yet public amenities such as schools and parks are in good distance to inhabitants enable them for walking. While public amenities in Al Max district need great consideration.	 <p>walkways need to be integrally converged as part of residential areas, and roofs of Al Max district need to be available for gathering and socialization.</p>
	Emergency accessibility		●				●		
	Easy accessibility to public amenities		●			●			
Environmental character	Clean environment			●			●	A pollution free environment with proper arrangements is a priority for the inhabitants, as a result of intervention of industries in Fes (leather, copper, pottery and carpets), thus a great amount of pollution and noise exist.	 <p>Reclaiming the canal in Al Max by simple ideas is suggestion to enhance the visual character, on the other side in Fes; the suggestion was transferring some industries to other spaces.</p>
	visual character			●			●		
	Housing density			●			●		
	Nonexistence of noise			●			●		
Planning, Land Use and housing	Building codes		●				●	Building codes in Fes El Bali are not implemented, that's because it was built in the past as a walled medina targeting intended issues related to defence, yet nowadays inhabitants are worried about this feeling confirming that mixed use buildings and not applying building codes are a source of nuisance and violations, while Al Max inhabitants registered their concern in the conversion of some apartments on the ground floor to stores is an essential demand to increase income although they don't prefer it.	 <p>Hotels in Fes are converged with the housing units, yet are not easy accessed, the same as the stores at the ground ribbon of the housing units, on the contrary the stores in Al Max are accessible to pedestrians , but need to be enhanced</p> 
	Mixed use			●			●		
	Mixed housing arrange of types, sizes and prices		●			●			
	Different services		●			●			
	Easy accessibility to residential areas		●				●		

## CONCLUSION

As stated before that the paper aims at determining the datum of accepted well-being community through determining a group of indicators to substitute the informal settlements to more reasonable rational settings. Shown in the previous table that The surveys' results were thoroughly analysed in order to reach livability due to inhabitants in



terms of seven categories; one is concerned with the SOCIAL UPGRADE, in which a public realm needed for many activities, such as celebrations, festivals and events that bring opportunities for its citizens to be together, could be achieved by outdoor plazas encompass stacking theatres, while the market is a dominant demand in both cities, for Fes el Bali specifically and because of intervention of industries; leather, copper, pottery and carpets, thus organized markets are a need, actually they are implementing this demand or in progress, yet the help is needed. Other six categories are related to planning; in which AESTHETIC QUALITY is not well perceived entails creating a sense of place and beautiful facades with good massing and fine details in which enables awareness raising towards beauty and good arrangements. QUALITY OF INFRA STRUCTURE, yet the availability of maintenance are one of their major needs to feel livability, however some participants thought of the futuristic approaches towards energy renewal and generation.

Most importantly, participants don't feel satisfied with SAFETY AND SECURITY to the maximum, especially when this indicator cause a conflict with meeting their social needs represented in selling their goods, hence there are street vendors either from the residential area or externals, as well as their social acceptance of residential area need to be increased, the solution can go for enabling walkways to be integrally converged as part of residential areas which in their views need to be planned along with driveways and complemented with suitable street furniture to encourage interaction among walkers, and also to be a source of surveillance. Moreover QUALITY OF LOCAL PUBLIC AMENITIES that relate to Location attributes as well as connectivity to city level amenities should be enhanced through Emergency accessibility and roof top buildings to be available for gatherings and socialization. Aspects of identity and character of the place, that most probably should signifies the residents' economic and social level are indicators related to ENVIRONMENTAL AND VISUAL CHARACTER, the identity of each community in the two cities is obvious, lacking only some issues like housing density arrangements and clean environments, only simple ideas are considered as suggestions to enhance the visual character such as painting the facades in Al Max by local materials and drawing graffiti on walls through a way of collaboration between the public sectors and a partnership. Moreover different services and mixed use buildings in Fes El Bali as well as non-easy accessibility to residential areas are all obstacles for gaining livability, thus PLANNING LAND USE AND HOUSING need a thoroughly consideration, with the concern that participants didn't suggest to segregate commercial and residential land use.

Throughout the research there was a challenge concerning how livability problems should be addressed in order to identify categories which in turn present the overall perceptions of the participants about essential elements of livability references, yet the research findings introduced an understanding of the local livability appeared clearly in the suggestions of many participants for how livability problems should be solved. Tailoring these suggestions is essential for gaining livability and social quality of life as well as proactive urban design. Moreover it has been proved in this paper that public spaces have a key role in gaining social sustainability, as they act as active urban spaces which offer the sphere for the physical, social, and economic changes in the poor areas towards enhancement of the quality of urban life, even by implementing simple ideas such as creating more shaded or covered areas as well as furnishing the streets with simple tools.

Finally, this research shows that cases chosen from Egypt and Morocco representing the Arab cities illustrated clearly the key role public spaces can act to improve the quality of urban life, through their potential opportunities, moreover the research validates the



hypothesis which states that activating the effective environments people create in their urban forms, will lead to prosperity and sustainable urban settings.

## References

- Balsas, C. (2004). Measuring the livability of an urban centre: An exploratory study of key performance indicators. *Planning Practice & Research*, 19 (1), pp. 101-110.
- Barkley, B. et al, (2017). Do low-income rental housing programmes complement each other? Evidence from Ohio. *International Journal of Housing Policy*, pp. 1-29.
- Brenner, P. & Brenner, L. (2007). Livability Initiative wake up call for Tasmanian Urban Planning. *Livability Planning Checklist*, 33, pp. 23-34.
- Carmona, M., et al, (2010). *Public Places Urban Spaces, the Dimensions of Urban Design*. Second Edition, USA: Routledge, pp.133-148.
- Carmona, M., et al, (2016). *Design Governance, the CABE experiment*. Routledge, pp. 120-131.
- Moor, M. & Rowland, J. (2006). *Urban design Futures*. Chapter 2, Globalizing urban design, the development world context, Routledge, pp. 30-36.
- Mullins, D. (2017). Achieving policy recognition for community-based housing solutions: the case of self-help housing in England. *International Journal of Housing Policy*, pp. 1-13.
- Nil, S. (2014). Emergent Trends in Architecture and Urbanism in Modern Cairo: Shifts in the Built Environment. In: SB International Conference Cairo 2014, Cairo, Egypt, 28-30 October 2014.
- Palich, N., & Edmonds, A. (2013). Social Sustainability: Creating places and participatory processes that perform well for people. *Environment Design Guide*, 78, pp. 1-13.
- Potts, D. (2011). Shanties, slums, breeze blocks and bricks: Misunderstandings about informal housing demolitions in Zimbabwe. *City*, 15 (6), pp.709-721.
- Satsangi, M. et al, (2010). *The rural housing question: Communities and planning in Britain's countrysides*, Bristol, the policy press, pp. 52-77.
- Taha, D. (2013). Place Identity of Egyptian Cities. *ACE: Architecture, City and Environment*, 2, pp. 7-10.
- The Economist Intelligence Unit (The EIU). (2017). *The Global Liveability Report 2017*, London, UK.
- UN- HABITAT. (2016). *Habitat 3 – The New Urban Agenda*. In: the United Nations Conference on Housing and Sustainable Urban Development 2016, New York, USA.
- UN- HABITAT & OHCHR. (2002). *Housing rights legislation*. Nairobi: UN-HABITAT, United Nations Housing Rights Programme Report No. 1, Series of publications in support of the Global Campaign for Secure Tenure No. 05, Retrieved September 24, 2016, from <http://www.ohchr.org/Documents/Publications/HousingRightsen.pdf>.
- Woodcraft, S. (2012). Social sustainability and New Communities: Moving from Concept to Practice in the UK. *Social and Behavioural Sciences*, 68, pp. 29-42.
- Yeun, B. & Giok, O. (2009). Challenges of Livability, Sustainability and Vibrancy. *World cities: achieving livability and vibrancy*, 65, pp. 1-12.
- Yu, Z. (2017), Macro effects on the household formation of China's young adults-demographics institutional factors, and regional differences. *International Journal of Housing Policy*, 17 (4), pp. 512-540.

# Towards a sustainable renewal of peri-urban neighbourhoods of single-family houses in Switzerland

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**Abstract:** Resulting from the society shift of the post-war period, urban growth and urban sprawl of infrastructure and settlements of individual housing are today at the centre of public policies' focus, in particular due to their widely criticized environmental impacts. If sustainable urban planning strategies aim at avoiding the construction of new peripheral residential developments, few studies question the future evolution of existing peripheral neighbourhoods – although their inhabitants will face increased economic, social and environmental issues in the coming decades.

The on-going research presented in the paper investigates the possibility of a sustainable renewal of peri-urban neighbourhoods of single-family houses in Switzerland by 2050. In this framework, the paper first defines the research framework characterized by the recent evolution of public policies. The revision of the territorial planning law (LTP) of 2014 intends to reorient future urban developments toward existing and well-connected built-up areas. The 2050 energy strategy and the “2000-W society” vision provide a framework to consider the overall energy transition in Switzerland, as well as specific targets to reduce households' overall energy consumption. Then the study presents the design framework of peri-urban renewal paths. It relies on the identification of peri-urban residential municipalities within the Swiss territorial context, and the elaboration of a pre-operational typology of peri-urban neighbourhoods of single-family houses. Finally, the paper presents four design scenarios based on a wide literature review and a series of interviews with urban planning and architecture experts to undertake a feasible renewal of existing peri-urban neighbourhoods of single-family houses by 2050.

**Keywords:** Peri-urban residential areas, policy framework, energy transition, design scenarios, Switzerland

## Introduction

Most current projects and designs focus on denser built-up areas of the urban-regions. The compact city vision considers the well-connected urban areas and does not provide any broad renewal strategy for the peripheral areas however exposed to growing environmental pressures (Rey, 2011). Nevertheless, low-density districts are more and more coveted and considered as an important land- and construction-bank showing a non-negligible potential for the production of new dwellings. Several exploratory approaches have started investigating a potential increase in density within single-family houses developments (ANR, 2011; Beyeler, 2014). They implement soft densification strategies to avoid individual property's constraints, and focus on private and individual motivations at the scale of a dwelling or a plot, leaving aside an overall vision at the neighbourhood or municipality scale.

The on-going *Living Peripheries* research, presented in this paper, aims at offering new ideas and concepts to investigate the adaptation capacity of existing peri-urban neighbourhoods of single-family houses to social and societal evolutions by 2050. It considers both the current sustainability challenges and research limitations, in terms of lack of overall neighbourhood scale vision and absence of specifically adapted strategies.

The first section of the paper focusing on the research framework, reports the recent evolutions of the policy framework and their restrictive impacts on territorial planning. The second part presents the composition, organization and specificities of the Swiss territorial

context and the resulting typology of peri-urban neighbourhoods of single-family houses. Those elements represent the design framework for four theoretical design scenarios introduced in the last section. They envision common trends and alternative paths to adapt peri-urban neighbourhoods by the horizon of 2050.

## **Research framework**

### ***Evolution of urban-planning regulatory requirements***

Considering the extent of urban sprawl, the Swiss administration and population were pushed to implement means to preserve their living environment (Rey, 2012). The policy framework about territorial planning has consequently been adapted to protect land and landscapes as non-renewable resources. The federal law on nature and landscape protection was the first to enter into force in 1966. However, it is not until mid-2000s and the awareness of a growth of urban lands at a pace of 1m<sup>2</sup> per second that the legislative dynamic soared. The initiative “some space for men and nature”, also called “initiative for the landscape”, intended in 2007 to introduce new legislative means to control urban sprawl (Salomon Cavin, 2015). Although this attempt was unsuccessful, it set the stage for both the revision of the federal law on territorial planning (LTP), approved by referendum in March 2013, and the federal law on secondary homes which came into force on the 1<sup>st</sup> January 2016. Both laws fix a strong framework on territorial planning and aim at stopping irrational land consumption.

LTP's ambition shows a will to discontinue current planning practices. It relies on two main principles: the preservation of landscape as a strong identity reference for the country, and the regulation of land consumption. The landscape preservation depends on the management of land uses, between agriculture, forest, built-up areas and natural spaces of leisure. According to LTP, any additional land consumption must be consonant with real demographic needs, with the public transport network, and with the principle of compactness and development towards the inside. The goal is to restrain urban sprawl and to promote high quality living environments and local amenities.

Two mandatory documents guarantee the implementation of the law at local level. (1) Based on a strategic and prospective vision of the region, the cantonal master plans define the distribution of land uses at large scale. (2) In compliance with the latter, municipal affectation plans outline the precise distribution of land uses on the municipal territory. In the case of planning new urban developments, their size depends on the expected needs in terms of housing for the next fifteen years. (CH, 2013).

Each canton is responsible for the implementation of the LTP at local scale by considering their own specificities. The cantonal master plan of Vaud implies significant constraints regarding the sizing of new built-up areas, especially when peri-urban planning is concerned. The document defends the idea of a strong network of centres. The aim is to maintain a hierarchy from cantonal centres to local centres. In order to translate this goal into urban planning the Canton attributes an annual growth rate to each municipality located outside the compact built-up areas, based on a prospective estimation of future demographic evolution. A closest observation of municipalities allows the attribution of an annual growth rate depending on the types of identified areas. In the more remote areas, the annual growth rate is limited to 0.75%, but in the centre of the village or in the well-connected areas, growth rate goes from 1.5% to 1.7%. The final sizing of new urban development areas depends on a theoretical living area of 50 m<sup>2</sup> per person and a minimal

density of 0.4 (State of Vaud, 2016). For instance, a municipality, which has a growth capacity of 100 inhabitants, is able to create a new development of a maximum of 12,500 m<sup>2</sup> to comply with the minimal density of 0.4 for the creation of 5000 m<sup>2</sup> of residential (living) areas.

The revision of the LTP and its interpretation in the Canton of Vaud clearly aim at containing urban sprawl. This context raises the issues of the transformation and adaptation of peripheral territories resulting from the urban expansion processes. They are located in the less attractive areas that have been attributed low margins of demographic growth. Nowadays, density is presented as the main solution to improve sustainability. However, according to the recent evolution of the policy framework, it appears difficult that density should be an exclusive answer for the dispersed urban areas transformation.

### ***Energy transition***

Facing growing environmental preoccupations, Switzerland has redefined its long-term energy strategy through a new energy law, approved by referendum in May 2017. The law aims at insuring “a sufficient, safe, cheap and clean energy supply” by fostering renewable energies produced in Switzerland. The new law complies with the theoretical framework of the “2,000-W society” vision used as reference to envision a long-term energy transition (Novatlantis et al, 2011). It sets gradual targets to achieve a reduction of the non-renewable primary energy (NRPE) consumption by 2050 and 2150. By 2050, intermediate objectives target a NRPE reduction to a mean power per person (MPP) owing to all aspects of life of 2,000 W and an annual global warming potential (GWP) of two tons of CO<sub>2</sub> equivalents (CO<sub>2</sub>e) per person. By 2150, the overall MPP should reach 2,000 W of primary energy (PE) including 500 W of NRPE and GWP should be limited to one ton of CO<sub>2</sub>e per person per year.

“The efficiency path for energy” (SIA, 2011) provides the normative framework for the energy transition of the built environment towards the 2050 horizon. It relies on specific targets for each building type and three categories of environmental impacts: (1) the building construction and materials (embodied impacts), (2) the use of the building (operational impacts) and (3) the mobility of the building’s users. This policy is very demanding for dwellings located in peri-urban residential areas, commonly composed of single-family houses with a bigger living area of 117 m<sup>2</sup>. The resulting average living area per person is 46.8 m<sup>2</sup> compared to 42.4 m<sup>2</sup> in urban centres (Fig. 1). Regarding mobility, the 2010 micro-census on mobility and transports (FSO et al, 2012) results show that peri-urban residential municipalities’ inhabitants have the most energy demanding mobility, with an average daily distance of 45.5 km and an almost exclusive recourse to individual car (73% of the travelled distances) (Fig. 2).

The challenge extent to reach the intermediate targets in the scope of the “2,000-W society” requires both a transformation of the dwelling stock, in terms of new construction and renovation projects, and an improvement of mobility practices. A previous study, which still has some ongoing developments, investigated the question of the compliance to the intermediate targets through a series of prospective theoretical scenarios (Drouilles et al, 2017a). It highlighted on the one hand how current construction practices combined with a reduction of the living area per person were able to meet the requirements. On the other hand, it showed how an evolution of lifestyles was essential to achieve the drastic reduction of the energy consumptions owing to mobility, along with the improvement of technical aspects.

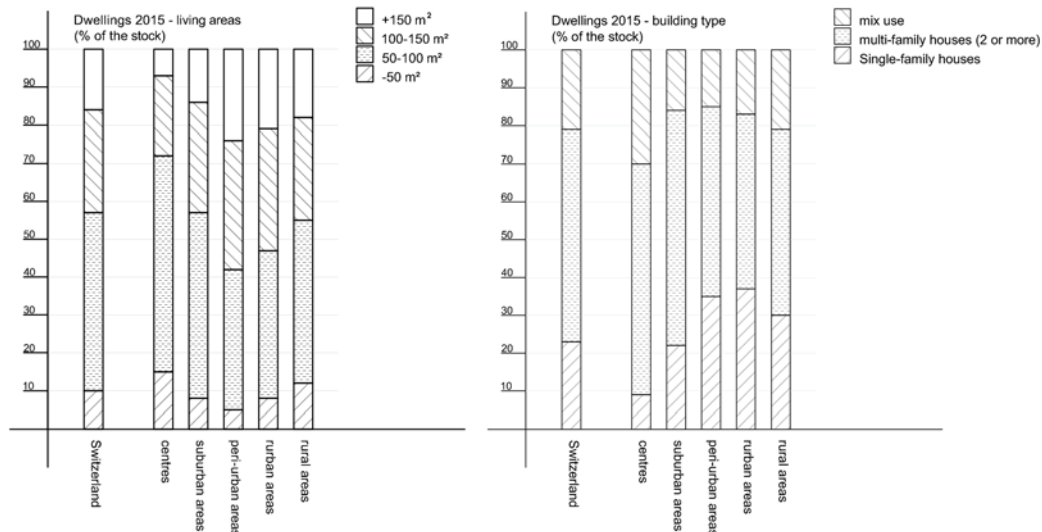


Figure 1. Dwelling stock features by territorial entity (FSO, 2015)

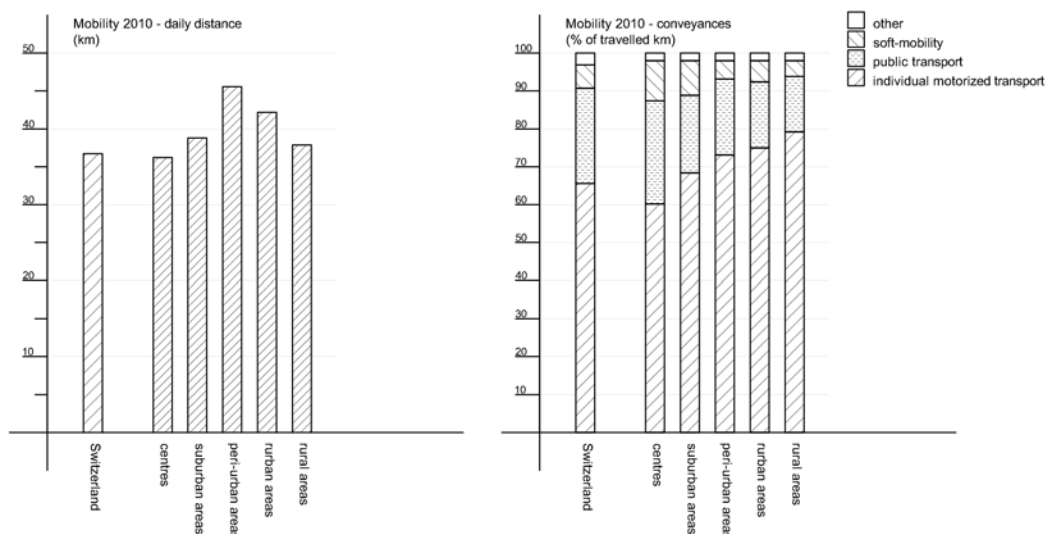


Figure 2. Mobility features by territorial entity (FSO et al. 2012)

## Design framework

### Urban features in Switzerland

In Switzerland, 84% of the population lives in urban areas among the 49 urban regions and 28 isolated cities (FSO, 2014). The urban continuum from Geneva to St. Gallen, encompassing Bern, Basel and Zurich (Fig. 3), bears witness to the metropolization process (Rey et al, 2015). The Alpine forests or peaks, unsuited for urban development, represent 58% percent of the 41'285 km<sup>2</sup> of the country. Therefore, most of the population gathers on the Swiss Plateau (from Geneva to St. Gallen). Given those peculiar topographic features, land is a limited resource to preserve.

In order to understand better the urban territories organization and diversity, the Swiss Federal statistical office (FSO) and the territorial planning office (ARE) built a new typology of "municipalities with urban character" in 2012 (FSO, 2014). The definition delimitates a wider buffer zone between urban centres and countryside areas. The



proportion of working commuters is the functional criteria used to identify the influence of the urban region on the territory. The newly delimited peripheral zone gathers the ‘urban-region’s other municipalities’, i.e. all the built-up areas dispersed outside the compact urban areas.

### ***Peri-urban residential municipalities***

The fast evolution and growth of cities leads to the constant redefinition of what is urban. In this context, the delimitation of a peri-urban territorial entity becomes a delicate question. The generalisation of urban areas due to the settlements’ dispersion and the progressive disappearance of the city/countryside duality are recurrent topics of debate (Schuler et al, 2004). Therefore, peri-urban areas have acquired a quality of buffer zone or “in-between” that makes the definition task harder (Sieverts, 2004; Da Cunha et al, 2015).

To clarify our words, let us briefly look at the vast territories of the “urban region’s other municipalities”. This category qualifies a buffer zone between two very distinct territories: (1) central and suburban municipalities, with an average density of 1’050 inhabitants per km<sup>2</sup>, and (2) multi-orientated or rural municipalities where the average population density is 70 inhabitants per km<sup>2</sup> (Fig. 3). The whole of the category is qualified as ‘urban’ although it clearly gathers a great diversity of areas. Current definitions underline the lack of concepts to understand the features of the peri-urban areas, which are neither entirely urban nor entirely rural.

To bridge this gap, our research project aims at building a subcategory within the “urban region’s other municipalities” category. Based on the state of the art of the peri-urban question, we listed six main mandatory components for the delimitation of the peri-urban residential municipalities (Tab.1) (Drouilles et al. 2017a). The goal was to target areas representative enough and under enough pressure to justify the design of transformation scenarios for the 2050 horizon.

Table 1: Identification criteria of the peri-urban residential municipalities

Criteria	Description	Source
1	Located within the urban-region’s perimeter	[FSO, 2014; INSEE, 2015]
2	More than one third of the working population commutes to the urban centre	[FSO, 2014; INSEE, 2015]
3	Located outside the compact built-up areas of the centre	[FSO, 2005]
4	Population density higher than 150 inhabitants per km <sup>2</sup>	[OECD, 2011]
5	More than 50% of single-family houses within the building stock	[Bauer et al, 1976; FSO 2005]
6	Population growth between 1950 and 2000, at least 30% in 10 years	[Garnier, 1984; EEA, 2006]

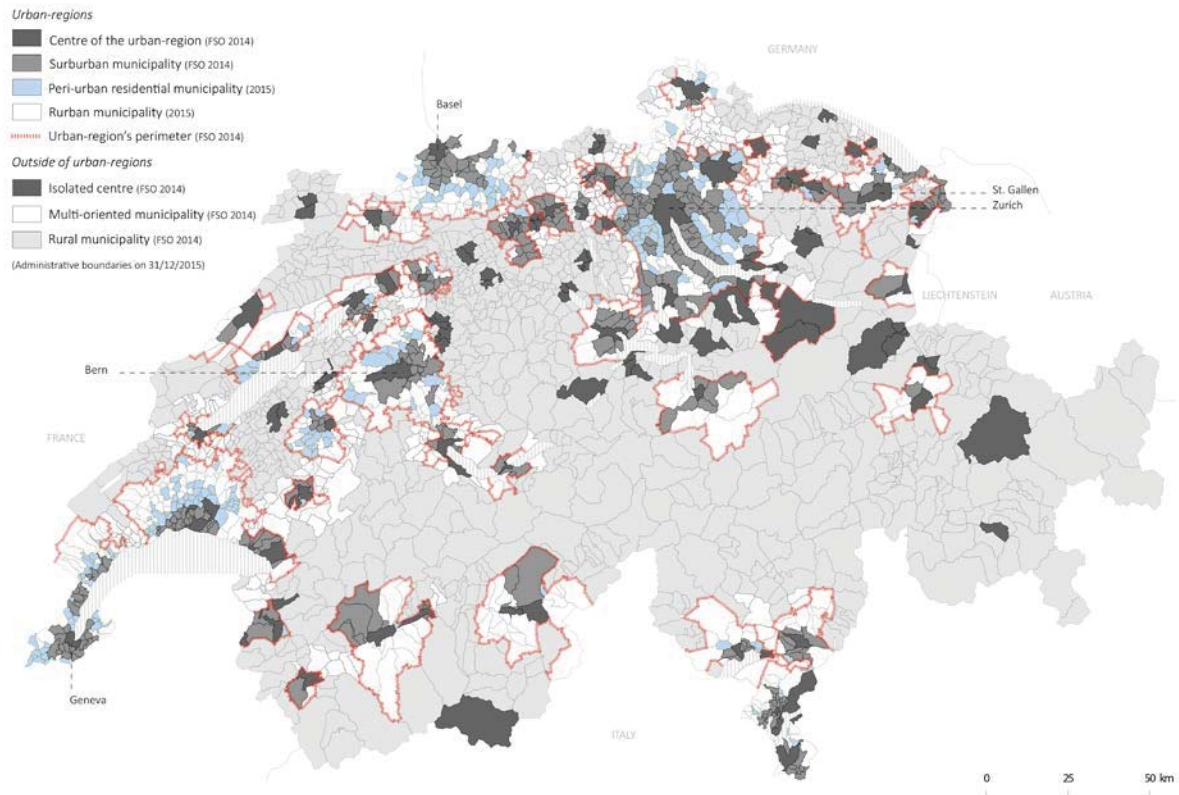


Figure 3. Swiss territorial entities and peri-urban residential municipalities. (FSO, 2012)

### ***Typology of peri-urban neighbourhoods of single-family houses***

Considering the challenges and constraints faced by single-family houses, several current studies investigate their future both from the point of view of the building's transformation (Beyeler, 2014) and from the conditions of their permanence in the territory (Bosshard et al, 2014). Designing evolution projects for those areas appears as the next coherent step of the research about the future of the dispersed urbanization. It is the ambition of the *Living Peripheries* research project to propose a decision support on the future of the peri-urban neighbourhoods of single-family houses based on the design of prospective transformation scenarios at neighbourhood scale.

A research by design workflow requires a strong framework to be reliable on and reproducible in further studies. In the scope of the *Living Peripheries* research, we chose to elaborate a typology of peri-urban neighbourhoods of single-family houses as a pre-operational tool. A pre-operational tool does not aim at building new knowledge but it rather provides a framework for an efficient design process (France, 1981). In order to do so, after the inventory of 138 neighbourhoods of single-family houses in the identified 38 peri-urban residential municipalities of the Lausanne's urban region, we built a typology based on three criteria – the distance to the closest train station, the date of the neighbourhood's first constructions and the neighbourhood size (Drouilles et al, 2017b). Those criteria influence the design process as explained below. (1) Depending on the location and the integration to the public transport network, LTP allows a higher growth rate to encourage the densification of the areas that benefit from a better accessibility. Moreover, the distance to the train station influences the type of alternative mobility scenarios proposed in a neighbourhood: soft-mobility means could be fostered rather than a heavier public

transport. (2) The current energy performance and future retrofit actions depend on the buildings construction period, in relation to the building age and the implementation of energy requirements. The neighbourhoods started in the 50s-80s are in a more urgent situation, considering the poor performance of buildings from this period (Institut d'architecture TRANSFORM, 2016). (3) The neighbourhood's size and population influence the design possibilities: more dwellings and population signify a higher demand in terms of equipment, mobility and amenities.

The resulting typology applied on the peri-urban residential municipalities of Lausanne gathers five types of neighbourhoods of single-family houses (Tab. 2). From each type, a representative neighbourhood was selected as case study to implement and assess several design scenarios to consider a peri-urban transition by 2050 (Fig. 4).

Table 2: Typology of peri-urban neighbourhoods of single-family houses in Lausanne  
classification criteria and average reference values (*n.* = *neighbourhoods*)

Criteria	Type 1	Type 2	Type 3	Type 4	Type 5
Distance to train station	< 1 km		> 1 km		> 1 km
First constructions	1950 - 1976		1950 - 1976		1976 - 2000
Neighbourhoods' size	> 5 ha	< 5 ha	> 5 ha	< 5 ha	< 5 ha
<b>Average values</b>	11 <i>n.</i> - 9%	8 <i>n.</i> - 6.5%	35 <i>n.</i> - 28%	43 <i>n.</i> - 35%	18 <i>n.</i> - 14.5%



Figure 4. 5 types of peri-urban neighbourhoods of single-family houses in the urban region of Lausanne. Each type is shown on a 500m x 500m square.

## Considerations for the future

The elaboration of four theoretical design scenarios for peri-urban neighbourhoods of single-family houses (Fig. 5) relies on several methodological steps. First, the elaboration of the typology allowed a better understanding of the Swiss context and the territorial integration of the peri-urban neighbourhoods. Then a literature review on societal medium term prospective evolutions revealed some common trends and strong signals (DATAR 2010; Moreau 2014; Kaufmann and Ravalet 2016). Based on those initial steps, we designed some exploratory propositions that were partly comforted, invalidated or completed by a series of interviews conducted in winter 2016 with fifteen urban planning and architecture experts. Finally, about 250 questionnaires distributed in spring 2017 among the five case studies, enriched the observation's findings. The final outputs provided a strong framework for us to enunciate four theoretical design scenarios for the adaptation of peri-urban residential

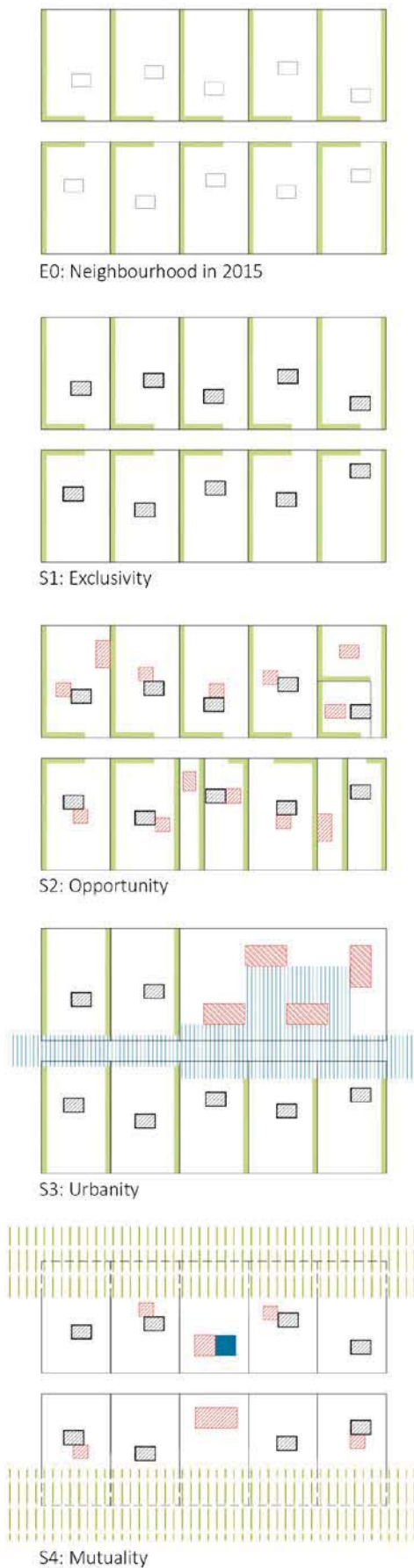


Figure 5. Theoretical design scenarios

neighbourhoods for the 2050 horizon. The scenarios rely on a proactive approach, which does not seek completeness but rather aims at being operational and feasible.

### **Exclusivity**

The scenario “Exclusivity” (Fig. 5 – S1) considers that single-family houses will become a kind of exceptional property in the context of the LTP’s application. According to the Canton’s strategy, urban development dynamics concentrate new constructions in the central area of the villages to ensure maintaining its vitality. The relative share of single-family houses in the dwelling stock is slowly decreasing to the advantage of denser constructions. These new dynamics will transform single-family houses into rare properties that are affordable only by the wealthiest households.

The scenario foresees a demographic stagnation and aims at the conservation of the exclusive and individual aspect of the neighbourhoods of single-family houses. Being an exceptional property, a single-family house represents a patrimony to be preserved. Therefore, the owners will try to maintain the value and identity of their property avoiding any subdivision of the plot or any excessive modification of the building. In most cases, the houses will only be renovated to comply with legal energy performance requirements. At neighbourhood scale, the investments are minor since the inhabitants’ lifestyles remain self- and dwelling-centred.

### **Opportunity**

The scenario “Opportunity” (Fig. 5 – S2) follows a mechanism of soft densification according to the current practice. It implements a neighbourhood renewal and relies on each plot opportunities. Each owner is the principal actor in the process. They assess their own individual needs to reduce or increase the living area, build a new independent settlement, subdivide their plot, or create a revenue stream.

Individual and private interests guide the transformations in this scenario. For this reason, the effects on demography are difficultly assessed



and controlled. The scenario implies the current life-styles perpetuation, but a higher social and functional mix is possible. Mobility practices still mostly depend on individual cars although some households, more sensible to environmental issues, could recourse to alternative conveyances.

### ***Urbanity***

The scenario “Urbanity” (Fig. 5 – S3) assumes a strong municipal involvement in the neighbourhood renewal. To address the specific issues of neighbourhoods of single-family houses – linked to economic limitations and constraints when selling or inheriting – a neighbourhood planning is developed from an analysis of the plots’ features and their economic implications.

This scenario refers to current practices in urban design and applies them in the peri-urban context. The neighbourhood renewal focuses on the development of a public polarity that works as an urbanity landmark and meets dwellings and equipment demand by (at least) 2050, in the framework of the LTP’s requirements. The feasibility of this scenario depends on a sufficient capital gain to finance the improvement of public spaces (e.g. increase of the pedestrian free flow, creation of public parking spots, etc.).

Neighbourhood planning allows a long-term prevision of needs as well as the intake of adapted solutions in terms of dwellings, equipment and services. The scenario also includes a mobility plan, which implements an alternative network with bike- and car-sharing systems. It aims at enabling the access to the railway network and reducing the car dependency.

### ***Mutuality***

The scenario “Mutuality” (Fig. 5 – S4) considers the peri-urban areas as laboratory to develop different concepts than those commonly applied in the current practice of urban design. This scenario questions the neighbourhood’s relation to its immediate environment, i.e. natural, agricultural and forest areas that surround it. It foresees a demographic growth according to LTP’s requirements.

Two main objectives of this scenario are an improved landscape integration and the development of shared activities. The landscape integration is achieved through the protection and the mutualisation of land to increase biodiversity and improve local food production. The feasibility of this scenario depends on the implementation of land and economic compensation mechanisms for the owners whose property loses value in the process of sharing and preserving soils. This compensation could consist in building bonuses or land compensations elsewhere in the neighbourhood, in an area more suited to receive higher density projects, e.g. closer to the historic built-up areas of the village centre.

The increase of shared activities in the neighbourhood relies on the development of several specific reference spaces used as associative or community rooms and involves communication and pedagogy activities to disseminate sustainable practices among the neighbourhood’s inhabitants.

### **Conclusion**

Current approaches supporting the built environment sustainability aim to encourage densification and urban renewal processes in the urban-region’s most attractive sectors. Numerous projects bear witness to the vitality of centres’ urban transition. However, it is unclear what the future of the low-density peripheral territories should be. They are usually



seen only as the compact and sustainable city's negative, but those territories are actually under strong constraints when considering environmental, social, energy or economic issues. Moreover, the solutions developed in the dense urban areas are neither adapted to the low-density areas where, for instance, the living environment already exceeds the objectives of revegetation rates, nor recommendable since it is not viable to promote density in all areas and increase the population dispersion on the territory.

Working on peri-urban areas invites looking at things from a different perspective. In Switzerland for instance, the recent adaptation of new laws at federal level, which clearly act to limit urban sprawl, strengthens this approach. Hence, the revision of territorial planning laws reduces the possibility to create new urban areas and promotes development towards the inside. Those elements and the highly performing Swiss public transport network make Switzerland an interesting laboratory for investigating the peri-urban topic.

In this specific context, the *Living Peripheries* project questions the adaptation capacities of peri-urban neighbourhoods of single-family houses through design. It considers several evolution paths from a stagnation and pursuit of current trends, to a transition towards new peri-urban forms. Four theoretical design scenarios assume four feasible paths to implement by 2050. The scenarios "Exclusivity" and "Opportunity" assume that the peri-urban neighbourhoods will stay outside the metropolitan development dynamics, either because the developments happen elsewhere or because the internal growth remains uncontrolled. The scenarios "Urbanity" and "Mutuality" assume both a connection to the larger scale through an overall planning and a proximity redevelopment with the implementation of local amenities.

The research innovates by considering peri-urban residential municipalities as experimentation sites and by designing scenarios at neighbourhood scale. Regarding the design scenarios' implementation into five real peri-urban neighbourhoods, a multi-criteria approach is used to achieve the integration of land, economic and temporal constraints. Within the timeframe of 35 years and adapted to each case study, the design options assume a population growth, a retrofit dynamic and economic constraints within the framework set by public policies and territorial features.

Following this design phase, each variant is assessed according to a series of sustainability indicators in order to provide a decision support to consider some sustainable peri-urbanism paths for each type of neighbourhoods. Based on the specific features of each types and each neighbourhoods, the research's next steps will show whether the peri-urban neighbourhoods of single-family houses are able to undertake adaptations that would benefit the community resilience to changes owing to a shift towards more sustainable behaviours, practices or lifestyles.

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## References

- ANR. (2011). *Le projet BIMBY en quelques mots | Bimby » Build In My BackYard* [online]. Available from: <http://bimby.fr/2011/01/le-projet-de-recherche-bimby-en-quelques-mots> [accessed 11 November 2013].
- Beyeler, M. (2014). *Métamorphose : transformer sa maison au fil de la vie*. Lausanne: Presses Polytechniques et Universitaires Romandes.

- Bosshard, M., Kurath, S., Luchsinger, C., Primas, U., Weiss, T. and Helfenstein, H. (2014). *Zukunft Einfamilienhaus?: Detached houses - the future?*. Zürcher Hochschule für Angewandte Wissenschaften, ed. Sulgen: Niggli.
- Da Cunha, A. and Hermann, L. (2015). Villes de l'entre-deux et entre-ville: penser l'intermédiation urbaine. *Urbia*, Intermédiation et hybridations: l'entre-ville reconsidéré(17), pp.10–18.
- Da Cunha, A. and Ruegg, J. (2003). *Développement durable et aménagement du territoire*. PPUR presses polytechniques.
- DATAR. (2010). *Prospective périurbaine et autre fabrique de territoires*. La documentation française. Available from: <http://territoires2040.datar.gouv.fr>.
- Drouilles, J., Lufkin, S. and Rey, E. (2017a). "Energy transition potential in peri-urban dwellings: Assessment of theoretical scenarios in the Swiss context". *Energy and Buildings*, May 2017.
- Drouilles, J., Lufkin, S. and Rey, E. (2017b). "Peri-urban communities in transition: transformation scenarios of neighbourhoods towards sustainability". In: *Proceedings of 33rd PLEA International conference: Design to Thrive*. Edinburgh: Network for comfort and energy use in buildings (NCEUB), pp.4787–4794.
- EEA. (2006). The impacts of urban sprawl. In: *Urban sprawl in Europe - The ignored challenge*. EEA report. Luxembourg: Office for Official Publications of the European Communities, pp.28–37.
- France. Plan Construction. (1981). Typologie opérationnelle de l'habitat ancien (1850-1948) : actes du colloque ("Vers une typologie opérationnelle..."), Royaumont, 10 janvier 1979 : (titre extérieur: Typologie de l'habitat ancien 1850-1948), Paris.
- Frank, F. and Rey, E. (2015). "Zone Villa: Grandeur et décadence d'un modèle". *Les cahiers de l'ASPAN, Le futur de la zone villa*, pp.4–11.
- FSO and ARE. (2012). *La mobilité en Suisse. Résultats du microrecensement mobilité et transports 2010*. Neuchâtel: OFS (Office fédérale de la statistique).
- FSO. (2014) Espace à caractère urbain, en 2012.
- Institut d'architecture TRANSFORM. Ed. (2016). Approche globale pour l'enveloppe du bâtiment : rénovation énergétique. Haute Ecole d'ingénierie et d'Architecture (HEIA) Fribourg. Fribourg.
- Kaufmann, V. and Ravalet, E. (2016). From Weak Signals to Mobility Scenarios: A Prospective Study of France in 2050. *Transportation Research Procedia*, 19, pp.18–32.
- Moreau, A. (2014). *Perspectives de ménages 2010-2030; Demande de logements et population active; Canton de Vaud*. Lausanne: Statistique Vaud.
- Novatlantis, SIA and Swissenergy. (2011). *Smarter Living: moving forward to a sustainable energy future with the 2000 watt society*. Bern.
- Rey, E. (2012). "Les démarches pour favoriser un développement territorial durable en Suisse". In: Nussaume, Y., Perysinaki, A.-M., and Sery, J., eds. *La maison individuelle: vers des paysages soutenable?* Études et recherches. Paris: Éditions de la Villette.
- Rey, E. (2011). *Quartiers durables. Défis et opportunités pour le développement urbain* [online]. ARE, O. fédéral du développement territorial and OFEN, O. fédéral de l'énergie, eds. Berne. Available from: [www.quartiersdurables.ch](http://www.quartiersdurables.ch) [accessed 21 October 2017].
- Rey, E. and Frank, F. (2015). "Métropolisation de la Suisse: entrave ou opportunité pour la durabilité ?". *Cahier spécial de TRACES: 8e édition du forum Ecoparc*, 6 November 2015.
- Rogers, R. and Gumuchdjian, P. (1998). *Cities for a small planet*. Icon Editions. Boulder, Colo.: Westview.
- Salomon Cavin, J. (2015). "La Suisse s'urbanise... tant mieux! " *Cahier spécial de TRACES: 8e édition du forum Ecoparc*, 6 November 2015.
- Schuler, M., Perlik, M. and Pasche, N. (2004). *Non urbain, campagne ou périphérie - où se trouve l'espace rural aujourd'hui ? Analyse du développement de l'urbanisation et de l'économie en Suisse*. Berne: ARE (Office fédéral du développement territorial).
- SIA. (2011). *SIA 2040 'La voie SIA vers l'efficacité énergétique'*.
- Sieverts, T. (2004). *Entre-ville: une lecture de la Zwischenstadt*. Marseille: Ed. Parenthèses.
- State of Vaud. (2016). 4e adaptation du plan directeur cantonal. Lausanne, Switzerland: Service du développement territorial. Available from: <http://www.vd.ch/themes/territoire/amenagement/lat-revisee/4e-adaptation-du-plan-directeur-cantonal/>.

# The untold story of the urban design practice of new cities in Egypt

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**Abstract:** This work reveals the untold story of the urban design of Egyptian new cities according to the nature of the singularity of the city. Singularity at various patterns is attempting to re-emerge with a shape distinctive from “us.” The meaning is that there will be a distinction, in post-singularity, from one city and the other. That is not only based on architectural form and formation but also in the differentiation of design ideas at the level of creating the city and the meaning stored in a hidden or inaccessible place in the public realm. The article comprises three questions: a ‘why,’ ‘what’ and ‘how.’ The first question is why the images of the new cities no longer affect the collective consciousness of the city residents like the traditional cities did? What made the absence of singularity of cities a dominant state? Moreover, how can be handle this lack of singularity possessed by cities? In perspective, the contribution of this paper is that it describes a new trend and concepts of urban design through which to suggest an innovative approach based on the idea of ‘Trans-Paradigms City’ and cities of singularity.

**Keywords:** City Imprint, City of Singularity, Singular Urbanism, Trans-Paradigm City, Urban Design.

## 92 years from Heliopolis to Al-Rehab

In the current era, some of the Egyptian cities passed through critical phases of the cities’ construction, either in the new settlements or the enhancement and enlargement of the current urban areas. It seems that new cities have emerged, and the features that indicate urban singularity have disappeared. The singularity is supposed to exist not only in new construction and living environments but should also be the result of generating innovative ideas that are always capable of creating a different product each time. This work supposes that the increase in the likelihood of producing similar cities, which will barely reach even the limit of conformity, is due to the domination of traditional Western urban planning and design paradigms in the fields of urban planning and design. Notably, the scope of work is not only careworn to monitor the repetition building and behavioural patterns or models that admittedly exist in the established and traditional cities. Moreover, the designer should focus on the selection of the relevant parts that are related to the identity and character of the city, which goes along with the concepts of ‘singular urbanism,’ ‘singular city,’ and ‘city imprint.’ This work explores the present fact of the ‘singularity’ in the ground reality through the comparison between Heliopolis (1905) and Al-Rehab (1997) as new satellite towns near Cairo, the capital of Egypt. Although the time gap between these two communities is 92 years, more than 90% of the respondents, today in 2017, pointed out that both communities are built based on the idea of suburban cities. However, this information seems to be incorrect, although André Raymond (2000, p. 331) mentioned that the Heliopolis is a suburb. Edouard Empain tries to follow Ebenezer Howard’s vision (1889) about the ‘Garden city,’ but he preferred “to create a satellite town near Cairo” (2006). In this vein, Al Rehab new residential complex follows the new urban assembly known ‘New Cairo.’ Those communities are similar for: (a) they are built outside the capital city, (b) they are sprawled around the major cities, (c) they have diversity and availability of services, green areas, restaurants, and hiking places, (d) they offer an environment combined with the best of town living and country living, and (E) the effectiveness of the accessibility by using vehicles and good pedestrian movement.

However, there are striking exceptions in the fact that the two settlements are similar. Heliopolis is an open residential area without walls or gates (not exceeding 5,888 acres -2.318 hectares). It had designed for European residents living in Egypt (Raymond, 2000, p. 331). While, Al Rehab is a huge gated community (approximately 220 acres - 86.61 hectares), designed for all people, either they are lives in Egypt or the foreigners who are coming to live from outside the country. Further, the differentiation appears in the styles of individual blocks' facades in Al Rehab, that are seemingly like or imitation the Western prototypes in the period of the modernist trend. In the other side, Heliopolis contain innovative architectural buildings followed the characteristics of Islamic art and ornamented to give "the city a certain charm" according to André Raymond (Raymond, 2000, p. 331). Also, referring to Heliopolis, Raymond (2000, p. 338) remarks it "...has a style of its own," it has been used the "Arab decorative motifs and the construction in the neo-Moorish style, for designing the facades," because of "...to preserve a certain authenticity." Consequently, Heliopolis nearly match an artistic artwork, from our viewpoint, referring to what Camillo Sitte describes in his book *City Planning According to Artistic Principles* (1889), afterwards, Aldo Rossi in his book *The Architecture of the city* (1966). Moreover, Heliopolis has a lot of urban artefacts designed by Alexandre Marcel such as the palace of Baron Empain inspired the design of Hindu-style temple or the Palais Hindu; the Basilica church, designed to be like Hagia Sophia in Constantinople, Istanbul; Triumph Square: Art wall and Roman column. In the other vein, by analysing the master plan of Al-Rehab city had been used the same intellectual underpinnings of traditional paradigms. Which is focused on the land use distributions in a structural hierarchy of the core components; services, urban spaces, and roads. Also, Al Rehab ignores the experience that results from the places.

Furthermore, it seems that the absence of the concept of 'singularity,' designing the city as an artwork, and design city 'piece by piece' as Jon Lang refers in his book *Urban Design: A Typology of Procedures and Products*. The last point that shows the fundamental differences between Heliopolis and Al Rahab is based on the morphological dimension. Notably, the societal transformations over the years, which produced structural changes not only in the urban tissue but also in the constructions. This issue did not happen definitively in Heliopolis, where the urban fabric is widely coherent. But it was occurred in the scope of the individual activities, like Maryland park, the buildings behind and in the front of the park, and several blocks in Al Korba region. While Al-Rehab did not experience these transformations, there is no luxury buildings or significant architecture, or even urban symbolic signs can change over time.

### Singular Urbanism

In some cities in developing counties, according to the author of this manuscript "there has been a turning point in both urban morphology and the construction of typological characteristics of architecture that have accompanied changes in urban lifestyles" (Abusaada & Elshater, 2017, p. 9). 'Urbanism' is a term that indicates the lifestyle of the city inhabitants, and the word 'singular' is used to signify especially excellent, distinguished, or remarkable property. Italian architect and thinker, Aldo Rossi (1966, p. 7), used the phrase "singularity of place" as peter Eisenman indicate in the introduction of Rossi' book *The Architecture of the City* to describe how "architecture gives form." Where, Rossi (1966, p. 106), believes singularity "beings in the event and in the sign, that has marked the event." As well as, he (1966, p. 127), sees "the singularity of any work grows together with its locus and its history, which themselves presuppose the existence of the

architecture artifacts.” This work presents the concept of ‘Singular Urbanism’ to show the lifestyle of city citizens as exceptionally magnificent. Also, it proposed ‘Singular City’ or ‘city of singularity’ not to be a new term, but also a mechanism can be used in the field of urban design.

This term allows for developing an approach that enables the city to be defined according to the multiplicity of singularity points in comparison to other cities. It concentrates on the new city that should be free of controlling of intellectual paradigms that constitute plenty of obligations—or utterly says it makes a fence of habituation from Western thought. Then, each city should be free to share its people in the consolidation of what may be appropriate to the characteristics that give it singularity. There should be a relative balance between the desires of a city's inhabitants from one side and the visitors who are coming for business or pleasure on the other side. Besides, it is necessary to make a separation between the urban areas a city's places should have according to two points: The first is a distinct singularity emerging from its ancient history and people's relations with these places, and other places which derive its individualities. Both are established on the new distinctive and unique features, from the design point of view—this is despite that its similarity is due to the era of globalization—or because these buildings rose to be the iconic buildings.

This work is consistent with Aldo Rossi, was according to the claim of Peter Eisenman (1982, p. 7), which belief that urban history leads “the process by which the city is imprinted with form.” Arguably, each new city needs to recognize individual semantics and symbols of differentiation, which helps to classify cities according to the organization and arrangement of their elements. Also, most of the topics that build those cities should reflect the nature of the residents and their sociocultural orientation, economic competitiveness, and environmental adaptability.

The aspiration of this term ‘singular urbanism’ is an emphasis on the intangible quality of the city compared with other cities. To work towards achieving the goal, the rights of all residents and visitors of the city should be respected, as well as those who pass the border to live, work, or engage in any activities in the city. To achieve this, everyone should be a partner in defence of the interests of the city as an excellent value, which exceeds the value of the individual. The city, in this case, becomes the locus of attention, and people themselves become enthusiasts of the city. Consequently, this will bring benefits to all who have the right to live in the city. Also, there was a problem addressed in the previous discussion; there are many issues in the form of an ostensible contradiction between two subjects. The first discusses the process that gives any new city its individuality to be different from any other city. The second is looking at the possibility that makes the prevailing paradigms as a gateway to the management of individuality via the tracking approaches carrying innovative ideas. The purpose of this manuscript is to highlight on the notion of the term ‘cities of singularity.’ It will pursue its search about difference and differentiation by using the term ‘singularity,’ and, how cities build its singularity?

### ***Cities of singularity***

Singularity means a city is not like any other city. The city should be entirely different from ‘the rest of the cities.’ Synonyms for singularity are difference, distinctiveness, individuality, particularity, and uniqueness the term city singularity expresses that idea that the quality of the city is unequalled. This singularity emerged because of accepting new urban design paradigms instead of the prevailing one which makes each city indistinct from all the rest; it means that each city, to be unparalleled (a haploid organism), should have a point of distinction which challenges



ideas. Each city should be a different entity and be able to improve itself autonomously over time. The aim is to make the city unmatched, unprecedented, and second to none. Which means, in the preliminary stages of planning and design of the new city, there is a need to emphasize the way of positive thinking, and how that enables one to begin a new vision before planning and designing any new city to become unique. Thus, the aim is to explore and develop the new paradigms in the discipline of urban planning and design in the field of architecture. Moreover, there is a need to develop prevailing traditional paradigms to achieve the real city's story, as appropriately adapted with its inhabitants, dwellers, and visitors. It is worth looking at how to select the parts that are relevant to this uniqueness, and which are consistent with the concept that this work poses—the “city imprint.”

### ***In the history of thought and our proposal***

In the nineteenth century, Camillo Sitte (1889) is the first one who sees the city “as a work of art” (Salmela, 2016, p. 184). This notion emerged during the debates around the differences between the roles of architects and engineers concerning the planning and designing of the city. The city as Sitte (1986, p. 260) stressing as (a) “an artistically effective city plan,” and (b) “a work of art and not merely an administrative matter.” In the 1960s and later 1970s, Aldo Rossi (1966), PULSA (1972), and Henri Lefebvre (1974) displays the city as “a work of art,” an “ultimate data,” and “an artwork system” (Eisenman, 1982, p. 7). Figure 1 shows comparative analysis about the city of singularity in the history of thought and the author assumption regarding the notions, concepts, objectives, urban artefacts, and the character. Singularity means a city is not like any other city.

### ***Today, in some European paradigms of Western thought***

Sociocultural dimensions are essential to the growth and protection of the singularity of any city—starting from the implementation of a local societal context to the creation of a cultural background and to understand and explain how the city works according to its components and the differences of its places. It is ended by reviewing the current and newest Western intellectual paradigms for selecting the best ones, or even for combining them between them to create a character that suggests or is inspired by the singularity of the city. Therefore, an architect should commit to everything that achieves quality, not depending on his view but through the criteria presented by theorists over time. It then adheres to all the standards that govern the classification of the city as a place where people go to live during the best time of their lives.

Architect should be respectful of the considerations of city is a technical information entity [technology is a society]; it is a commodification [making places famous]; it is an entrepreneurship [a city is a renowned object]; it is a trans-culturalism locus [difference and diversity]; it is empowering [making the city by people and vice versa]. Finally, in this work, city is in front of the temper of the times [ambiguity]. Although all these years have passed and we are now in 2017, the question remains whether the influence of the industrial age has led to the disintegration of the traditional city and urban expansion. Did it also cause the presence of new cities reproduced, duplicated, and produced far from the required artwork in the cities? Thus, this chapter will begin with the discussion of six paradigms for city planning and design that have arisen since the nineties in the last century. They include global and informational cities (1989), city branding (1990), smart city (1997), Cosmopolis/transcultural cities (2003), organic urban development (2010), and a great city (2010).

In the history of thought		The proposal
Since the nineteenth century 1889 (Sitte, 1986), (Ellin, 1999), (PULSA, 1972), Lefebvre (1974), (Lynch, 1984), (Dewey, 2008), and (Nadal-Melsió, 2008)		2016, Almost, in the mid-year.
	<b>1 The vanguard</b>	<b>By the author</b>
Artistically effective city plan is a work art, not merely an administrative matter.	<b>2 The notions</b>	Singular urbanism; city should be different from the other cities.
(a) City as a work of art. (b) The artefact system is an art object.	<b>3 The concepts</b>	(a) a city is not like any other city. (b) achieving the "singularity of place."
(a) The city is an 'artwork,' and 'artefact system.' (b) Separate from nature. (c) Should be pursued as a meaningful quality. (c) A history of space: explain the development and should not be distanced in any way from the history of time.	<b>4 The objectives</b>	(a)The lifestyle of city citizens as exceptionally magnificent, and (b) City as a work of art.
(a) Individuality, locus, memory and design affect on urban artefacts. (b) The efforts of the previous generations present an integrated work. (c) Architectural monumental unity due to the historical accumulations. (d) Embracing the practical, the symbolic, and the imaginary. (e) Managed and experienced as if they were works of art. (f) Experience as an art of sharing where nothing is missing.	<div><div><b>5 Cities of singularity</b></div><div>Urban Singularity [US]</div><div>(a) Urban history imprinted the city with form. (b) In the event and the sign that has marked the event. (c) Based on urban architecture artefacts. (d) Landmarks are the essential physical characteristic. (e) Figure-background clarity is necessary.</div></div>	
Is (a) Characterized by their history and form. (b) A work of art. (c) An intended landscape. (d) Today, city is the largest urban artefact system in existence. Individual semantics and symbols.	<b>6 Urban Artefacts [UA]</b>	(a) Architecture, individual semantics, and symbols (Rossi, 1982, p. 32). (b) Characterized by their history and form (Rossi, 1982, p. 29). (c) The city itself as a largest artefact system (PULSA, 1972, p. 208). (d) The products of all contemporary paradigms. (e) People.
(a) [UA] and its architecture "are the same. (b) The relative autonomy of architecture order. (c) The beautiful city has good architecture; it makes real the aesthetic intentionality of urban artefacts. (d) The dynamic of the city. (e) Everyday life in the city is profoundly related to all activities and encompasses them with all their differences and their conflicts.	<b>7 Character</b>	(a) 'Urban artefacts,' and 'landmarks' carries a remarkable character that is unconventional or singular in an urban context. (b) The nature of the residents and their socio-cultural orientation, economic competitiveness, transculturalism and social interactions. (c) cities for people and by them, sustainable, livable, loveable, informational, brand, smart, organic, great.
		<b>Plus</b> By the author (2006), based on literatures.

Figure 1: Singularity in the history of thought and what is the writer's assumption.

Each paradigm commenced based on a clear notion of the city as follows: The first is a technical information entity [technology is a society] (Castells, 1997, pp. 5, 21, 500) (Castells, 1996, p. 417) (Stock, 2011, pp. 964-968) (Lor & Britz, 2007, pp. 390-391) (Greenberg, 2000, p. 230). The second is a commodification [making places famous] (Anholt, 2010, p. 7) (Hankinson, 2004, p. 111) (Kavaratzis, 2004, pp. 55-66) (Ashworth, 2009, p. 9) (ISO/IEC JTC 1, 2015, p. 2). The third is an entrepreneurship [a city is a renowned object] (Hollands, 2008, p. 303) (Bouton, et al., 2013, p. 3) (Susantia, et al., 2016, p. 195) (Begg, 1999, pp. 798-800) (Nam & Pardo, 2011, p. 284) (Susantia, et al., 2016, p. 195). The fourth is a trans-culturalism locus [difference and diversity] (Savitch, 2010, p. 43) (Talen, 2006, pp. 236, 243) (Bloomfield & Bianchini, 2002, p. 6) (Hannerz, 1996, pp. 56-57) (Fainstein, 2005, p. 3) (Hadjicostandi, 2007, pp. 5154-5155) (Landry & Wood, 2008, pp. 321-324) (Council of Europe, 2013, pp. 25-26). The fifth is empowering [making the city by people and vice versa] (Schilders, 2010, pp. 29-34) (Osterman, 2015, p. 104). Finally, in this work, the sixth city is in front of the temper of the times [ambiguity] (Warnaby, 2009, p. 413) (Savitch, 2010, pp. 42-45). The nations are the technical information entity and technology is a society, commodification, entrepreneurship, interaction across cultures, goes hand in hand with another management mission, and What makes a great city great? While the concepts are: a process not a place, gain a competitive brand value, a high-tech variation of the entrepreneurial city, difference, diversity, and ultimately equality of locus, people make their city, and they should be empowered to make it, loose and suffers from ambiguity. The objectives are evaluating the progress of a country towards a society, altered the real material city to conform to the idealized image of the brand-name city, follows the Kyoto Protocol, and Citizens should enjoy regarding to their city's prosperity, understanding diverse cultural backgrounds of people, a spatial and social sense with spirit and dignity, and Concentrate activities on a bounded location. Also, as Abeer Elshater believes that "[h]appy people not only know that happiness is a choice, but also that it is a reaction to the present conditions of a community." (Elshater, 2016, p. 348)

## Discussion

The first phase of the interviews focuses on Al Rehab city, the exploring of the importance of the issue of singularity has needed 100 persons, includes 60 of inhabitants (40 men and 20 women) and 40 of guests (20 of both sexes). The first set of researcher's questions were as follows: 1. Do you find in your city that scenery can make the history of the city and distinguish it about shape, like the Big Ben in London or the Leaning Tower of Pisa? The answers were categorical denials (100%). 2. Is the city competitive and global? The answers were: (a) (70%) It is local, not global, but it is certainly competitive due to its integrated services and recreational areas; (b) (30%) The city is not competitive at all. 3. What is your opinion about the multitude of cultures and the diversity of the population and visitors? The answers were: (a) (60%) The city includes residents of the Arab world, (b) (40%) The proportion of foreigners does not exceed 2% in the city. 4. Does the city have advanced technology (or smart)? The answers were: (a) 85% believed that they have all the technical and comfort means and advanced infrastructure and networks; (b) 15% do not see it as a smart city because there is no internet network linking the entire city, and the buildings are traditional and non-green. The second set of questions focused on the vision of the construction phase and the contribution of the residents or whether the society is fully planning, designing, and implementing from the beginning. (a) 96% showed that the participation of the population is almost non-existent, the construction is carried out by the owner by repeated construction models, construction is carried out in phases in the neighborhoods, but the architectural design is done by

one design authority [we do not want slums]; (b) 4% believe that there is some participation in construction in the villa areas, but it is not noticeable. Afterwards, the author of this manuscript sees that the results would be more reasonable; after meditation, if the questions took the form of a comparison between two cases, one of them famous and well known to everyone. Bearing in our mind the expectation that quite a few of respondents will tend to be choosy where they live, driven by the influence of the term of topophilia for Yi-Fu Tuan-do not saying nerve and bias to a location, but based on the nature of “love of place.” In consideration, among elderly sympathisers with ‘Heliopolis,’ and the new generation of young people who they biased toward ‘Al-Rahab’ on the other side. Therefore, whenever the author notices a striking tone of bias, he realises that no response to this answer should be considered.

Nevertheless, the results that came were opposed to expectations. (83%) Of the elderly and youth, men and women, felt that ‘Al Rehab’ as the most acceptable of the Heliopolis, while 17% said that the aromatic place in Heliopolis still attracted them to go and enjoy it with along the other friendly places. But what cleared up the confusion was the arrangement of the singularity determinants as follows: management of place (23%), security (19%), green areas (15%), and infrastructure (services and facilities) (12%). These elements were in the forefront of the analyses arrangement that led the majority to prefer Al Rehab. Meanwhile, concerning Heliopolis, these determinants were rearranged as follows: management of place (0%), security (2%), green areas (4%), and infrastructure (services and facilities) (2%). Thus, the admiration of the participants towards Heliopolis appeared in an arrangement of determinants as follows: provision of urban artefacts (22%), architecture (18%), human experience (15%), pedestrian walkways (14%), and the city as an artwork (14%). There appears a different arrangement in Al Rehab: provision of urban artefacts (0%), architecture (6%), human experience (3%), pedestrian walkways (6%), and the city as artwork (1%). Moreover, the rest of the determinants were in Al Rehab and Heliopolis as follows: vehicle network (8% and (3%), technology (information and communication) (7%) and (0%), and accumulation and construction in phases (0%) and (6%).

The most critical conclusion is that our research assumption did not come in line with people’s beliefs. In ‘Al Rehab,’ the top determinants of the city of singularities, such as the presence of good architecture, urban artefacts, accumulation, and construction on phases, and a city as artwork gets in a late position, while city management, security, and provision of infrastructure takes a higher percentage. Concerning Heliopolis, their choices were reversed. This result left a strong impression for the researcher that the city today, in the technical-cognitive era, has become a product that offers the necessities of contemporary life before thinking of that city as artwork. And, that the primary determinants on which the citizen builds his views have nothing to do with the city’s physical design, but it is related to security and the extent of the city management’s success in meeting their requirements and basic needs at once. The determinant demands of modern life come later. I think this is what led Western urban planners and designers to invent their contemporary intellectual models.

The paradigms of the informational city, branding city, and smart cities started in the 1970s and has continued until now; they did not ignore, side by side, the paradigms that people respect, like cities for people, multiculturalism cities, and organically developed cities. Consequently, I decided to turn the research inquiries to focus on the desire to recognise the extent of the importance of the term ‘a city of singularity,’ which stands for the critical issue of our work, and it appeared that the following answers showed that the earlier answers had been becoming in

doubt. Although 70% of the respondents confirmed that the image of Al-Rehab does in the memory of the viewer what exactly Heliopolis does, the appreciation via Al Rehab happens because of differences in the reasons for the reactions which begin in Heliopolis. For the sake of certainty, 85% of the respondents showed that Al-Rehab had left an impressive impression than any other new or existing cities. The respondents arranged their views concerning the determinants of singularity as follow: (a) availability of contemporary paradigms (35%); (b) Architecture that have implications, signs, and symbols (27%); (c) Presence of urban artefacts (20%); (d) Involvement of user in design stages (9%); (e) design in stages (5%); (f) The absence of traditional paradigms (4%). Notably, in the present era, the resident of the city builds all his ambitions on the advantages that have been presented by applying contemporary Western paradigms. On the contrary, he rejects the dominance of traditional paradigms altogether, which only give boring repetitions in life. This is clear from the fact that although most of the participants in the survey emphasized the importance of the presence of good architecture and urban artefacts to achieve “singularity,” these determinants occupied a late arrangement in their answer to the reasons for the uniqueness of Al-Rehab. However, in another context, some of the participants pointed out that they are important determinants from a pure art viewpoint. They even believe that for the city to appear as an artistic work: “We are looking for priorities and preferences; security, management and modern life, and will come later; art and beauty.” Gracefully, one of them has intervened: “If you can give all of this, we will not reject utterly.”

This discussion above led us to be having more desire to listen to other views of some residents of Al Rehab and Heliopolis about the concept of singular urbanism in general; then, I decided to ask a direct question. At present, particularly concerning the concept of “singularity,” what is the sense of viewer, either was resident or visitor, about the state of new Egyptian cities? Abruptly, I found myself in the face of two different paths. The first path is that 35% they are not an interesting issue; further, it seems they do not care about this concept from near or far. Where the first important thing now is how to find place meets all the life needs, adding “now we are not in the field of competition with any cities.” The second path is that 65% believe that the Egyptian cities do not interest the concept of a “singular urbanism,” they are not only repeated images of each other, but also it is certainly not innovative and does not match the Western cities, or even historical Egyptian cities. Regarding what are the reasons behind the absence of the influence of the singularity of the new city on the collective consciousness of the residents of the city. (80%) Of the participants see that happens because these cities can no longer meet the requirements of modern times and in line with the indicators and rules of the concept of ‘singular urbanism.’ (20%) believes that happens due to deliberate negligence in the planning and design stages associated with the stages of the emergence of singularity at the level of the city structure.

## Findings

The summing-up of the earlier intellectual discourse and the survey based on the group interviews and the direct observations have indeed revealed to the researcher that the question of singularity is a social responsibility and not an individual issue concerning just the architectural task. The meaning is that most of the residents and visitors should have incentive programs to find the notions of difference, diversity, and singularity. For instance, how can the creation of new Egyptian cities enjoy a sense of differentiation as in the Fatimid Cairo? How can these new cities become like Venice, Rome, London, Paris, and like Graz in Austria? Of course, the answer



will not be a merely academic matter or the following-up of personal whims as the question needs to research the singularity of these cities, which is stood for mainly in their architecture and artifacts. Then, the author should look for how can be override the individuality in design and the transition toward an integrated plan, which will follow an urban design trans paradigm approach. This manuscript writes down that the key of 'cities of singularity' lies in how to activate all historical, symbolic, cultural, economic, and humanitarian aspects with a constant and relative balance at the same time. The first side is the history, which is relevant to drawing the lines of what must be the urban history of the new city. (a) History leads the process by which the city is printed in a manner consistent with its subject, which expresses the nature of its residents, their social and cultural orientation, their economic competitiveness, and the degree of harmony between the city's environment and quality. (b) History is interpreted through the relationship between the collective memory of events and the singularity of place. (c) History helps us to understand the complexity of urban artifacts-- which derives urban singularity from them—which form in the future its urban features and work as some incentives to know them later and treat them as urban symbols. Symbols is the second side, which (a) offers mighty significances on the nature of each city. (b) It can be ordered according to its unique elements. The third side is related to how to deal with the complex social, economic, and technical systems next to the architectural aspects. The design of any new city needs a flexible plan that gives a high priority to the present and future. "Trans-disciplinary design approach" should be used as considering social, economic, and technical systems along with architectural aspects. Consequently, A successful plan should consider the following. (a) Embrace multiculturalism based on racial differences without discriminating, including the promotion of citizenship and the right to be different. (b) Have a forward-looking strategy that protects the rights of future generations. (c) Increase competitiveness through investment in high-tech capabilities. (d) Promote socio-cultural planning principles: administrative, social, cultural (traditional), economic, and technical.

### **Why should be changing the lane?**

This manuscript concluded with two basic ideas: Scientific progress is inevitable, and its impact on the design of cities is inevitable. Today, the design of the Egyptian city according to the traditional European paradigms of Western thought alone is not enough, particularly if the goal is to create singular cities. Other intellectual samples have been developed and have become prevalent in Western thought, beginning with the idea of sustainability, through informational, multicultural, smart, and even great cities that combine all these paradigms in a competitive technical potency. Even the idea of integrating these logical models into their areas of competence is no longer proper, but the integration of knowledge and the emergence of innovative hybrid results are the basis. Thus, taking advantage of a cross-disciplinary approach is a major issue in scientific research around competence. The matter of "city of singularity" means to show the city to its inhabitants and visitors in a way that is different from any other city. The theoretical findings on this issue suggested that singularity is not only a description of the city as a commodity, information, intelligence, or sustainability, as much as the need for architectural connotations that highlight this singularity. These paradigms should be present as essential elements to be achieved in the city, such as utility, economy, technology, and beauty.

Three first singularities of the cities—in this work—can be drawn: the urban singularity (art form and transcultural city), economic singularity (city commodity and branding), and

informational singularity (informational city). These differences enable examining relations and picking three indicators for urban cities represented in quality, knowledge, and power all of which can create a composite character to the city of singularity. The interrelationship between power, quality, and knowledge refer to the possibilities of looking ahead by enhancing the ability to think, express, and act. Additionally, the conception of the new city needs not merely stimulating all the architectural disciplines and what is related in the other support areas, but also, it is an attempt to use a transdisciplinary approach. That means exceeding the step of joint work to present a new product, and crossing to create a different artwork has a singularity. First and foremost, respecting all the principles brought forth urban designs like sustainability, diversity, democracy, social equity, economic health, transcultural connections, technological developments, artistic and intellectual experiments, leadership, city making, city management, and citizenship and accommodating.

### **Lessons learned**

This manuscript makes the claim that the planning and design aspects of new cities need to enhance the efforts of architects (the ability of planners and designers to present innovative ideas, adapted to the requirements of the contemporary Egyptian city, is related to the notion of a city's singularity). This can be done through top decision makers, dominant controllers of capital, and stakeholders, i.e., all the parties concerned making a commitment to resolve the critical global issues that most affect the design of Egyptian cities. Cities should be productive, valuable, livable, lovable, sustainable, global, transcultural, intelligent, and for everyone—according to some dominant European paradigms—and designers should be oriented to ideas that are contemporary and built on transdisciplinary, hybrid, urban design, introducing a trans-paradigm approach. Building those new cities should be based on three concerns: the first is the capitalist economy where the city relies on a massive investment project that generates distinct returns without violating the principles of traditional human values, understanding them from a contemporary perspective. The second is the administrative, regulatory, and legislative factors that make the city an organized entity governed by forces that do not neglect the issues of identity, uniqueness, and singularity. The third is the construction elements: architecture does not depend solely on Western paradigms—even if they are genius—and there is not enough space to discuss their importance and impact, in history, on the art of the city. Finally, the most important aspect of these concerns is how to make the city an artwork, besides integrating the requisite up-to-date features.

Egyptian cities need to be seen like historic cities that have left behind extraordinary artefacts. The planner and designer architect should take from those paradigms, including its movements and schools. As well as, what was produced by the resulting theories, approaches, and trends of architecture to be an approach and innovative trend of urban design; its concern is city planning and design in general, and in Egyptian cities particularly. And, from it, to expand the circle of the presentation of theories related to form and formation of the levels of design starting from house and place to the city, which this research calls “a trans-paradigms city approach,” taken from the available paradigms—Arabian and European—to present a contemporary Arabian paradigm, taking into consideration the conditions for the development of a city print. It is based on opening the way for the stakeholders of the planners, designers, administrators, investors, and permanent users residing and visiting to present innovative ideas

through new visions, with respecting the concept that any new singular city needs the effort and time. One of the lessons learned from this work that will have a direct influence on the professional practice is that education in the realm of architecture (in the field of urban planning and design) needs more emphasis on teaching and learning how to present innovative ideas at multiple levels. The first-level concerns proposing the latest ideas about the uniqueness of the city through its wholeness image, which is the issue related to the theme of designing the city about economic, investment, and entertainment orientations. The second level concerns basic planning units where each district and neighborhood unit should have a singularity follow from the reflections of its activities. The third level concerns respecting the concept of the public realm of the city by activating the concept of singularity in urban spaces and collective buildings that overlook those spaces with a concern for the singularity of the tracks of traffic for cars and pedestrians. The fourth level concerns the singularity of the individual building and how to make single blocks have a symbolic and continuous singularity with time to become iconic architecture or artefacts. Finally, the most important aspect of these concerns is how to make the city an artwork, besides integrating the requisite up-to-date features.

## References

- Abusaada, H. & Elshater, A., 2017. *Back to the Order: The Chaos in the Cities of Hardship*. Germany: Lambert Academic Publishing.
- Anholt, S., 2010. Definitions of place branding –Working towards a resolution. *Place Branding and Public Diplomacy*, pp. 1-10.
- Ashworth, G., 2009. The Instrument of Place Branding: How is it done?. *European Spatial Research and Policy*, 16(1), pp. 9-22.
- Begg, I., 1999. Cities and Competitiveness. *Urban Studies*, 36(5-6), pp. 795-809.
- Bloomfield, J. & Bianchini, F., 2002. *Planning for the Cosmopolitan City: A Research Report for Birmingham City Council*. Leicester: Comedia, International Cultural Planning and Policy Unit.
- Bouton, S. et al., 2013. *How to Make a City Great?*, McKinsey: McKinsey & Company.
- Castells, M., 1996. *The Rise of the Network Society*. London: Blackwell.
- Castells, M., 1997. *The Power of Identity, The Information Age: Economy, Society and Culture, Vol. II..* Cambridge MA; Oxford, UK: Blackwell.
- Council of Europe, 2013. *The intercultural city step by step: Practical guide for applying the urban model of intercultural integration*, Strasbourg Cedex: Council of Europe Publishing.
- Dobrowolska, A. & Dobrowolski, J., 2006. *Heliopolis, Rebirth of the City of the Sun*. Cairo: The American University in Cairo Press.
- Eisenman, P., 1982. Editor's Introduction by Peter Eisenman. In: *The Architecture of the city*. Cambridge: UK: MIT Press, pp. 3-11.
- Elshater, A., 2016. The Ten-Minute Neighborhood Is[not] a Basic Planning Unit for Happiness in Egypt. *International Journal of Architectural Research*, pp. 344-357.
- Fainstein, S. S., 2005. Cities and Diversity: Should we want it? Can we Plan for it?. *Urban Affairs Review*, 41(1), pp. 3-19.
- Greenberg, M., 2000. Branding Cities: A Social History of the Urban Lifestyle Magazine. *Urban Affairs Review*, 36(2), pp. 228-263.
- Hadjicostandi, J., 2007. urbanism/urban culture. In: G. Ritzer, ed. *The Blackwell Encyclopedia of Sociology*. Australia: Blackwell Publishing, pp. 5154-5159.
- Hankinson, G., 2004. Relational Network Brands: towards a conceptual model of place brands. *Journal of Vacation Marketing*, 10(2), pp. 109-121.
- Hannerz, U., 1996. *Transnational Connections: Culture, People, Places*. London: UK: Routledge.
- Hollands, R. G., 2008. Will the real smart city please stand up? Intelligent, progressive or entrepreneurial?. *City*, 12(3), pp. 303-320.

- ISO/IEC JTC 1, 2015. *Smart cities*, Switzerland: Information technology.
- Kavaratzis, M., 2004. From city marketing to city branding: Towards a theoretical framework for developing city brands. *Place Branding*, 1(1), p. 58–73.
- Landry, C. & Wood, P., 2008. *The Intercultural City: Planning for Diversity Advantage*. UK and USA: Earthscan.
- Lor, P. J. & Britz, J. J., 2007. Is a knowledge society possible without freedom of access to information?. *Journal of Information Science*, 33(4), p. 387–397.
- Nam, T. & Pardo, T. A., 2011. *Conceptualizing Smart City with Dimensions of Technology, People, and Institutions*. USA., College Park, MD, pp. 282-291.
- Osterman, A., 2015. The Empowerment of ‘Self Power’. *Self-building City*, 6 5, Volume 43, pp. 104-107.
- Raymond, A., 2000. *Cairo*. London. England: Harvard University Press.
- Rossi, A., 1966. *The Architecture of the City*. Cambridge: UK: Oppositions Book, The MIT Press.
- Salmela, U., 2016. Planting New Towns in Europe in the Interwar Years: Experiments and Dreams for Future Societies. In: H. Meller & H. Porfyriou, eds. *Urban Aesthetics and National Unity: A Finnish New Town in the Making*. Cambridge: UK: Cambridge Scholars Publishing, pp. 177-194.
- Savitch, H., 2010. What makes a great city great? An American perspective. *Cities*, Volume 27, p. 42–49.
- Schilders, P., 2010. *The Organic City: Method or Metaphor? The Meaning of ‘Organic’ in Architecture and Urban Planning*. The Netherlands: International New Town Institute.
- Sitte, C., 1986. *City Planning According to Artistic Principles*. Mineola, New York: Dover Publications, INC.
- Stock, W. G., 2011. Informational Cities: Analysis and Construction of Cities in the Knowledge Society. *Journal of the American Society for Information Science and Technology*, 62(5), p. 963–986.
- Susantia, R., Soetomoa, S., Buchoria, I. & Brotosunaryo, P., 2016. Smart growth, smart city and density: in search of the appropriate indicator for residential density in Indonesia. *Social and Behavioral Sciences*, Volume 227, p. 194 – 201.
- Talen, E., 2006. Design That Enables Diversity: The Complications of a Planning Ideal. *Journal of Planning Literature*, 20(3), pp. 233-249.
- Warnaby, G., 2009. Towards a Service-Dominant Place Marketing Logic. *Marketing Theory*, 9(4), pp. 403-423.

# Promoting measurable indicators for sustainable development of open areas in neighbourhoods-with special reference to Khartoum Town-Sudan

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**Abstract:** The research reported in this paper identified indicators for sustainable planning of open areas in neighbourhoods. The research was performed in the new residential developments in Khartoum Town (El Riyadh (1972), Nasr Extension (1972) and El Mujahedeen 1988), compared to older neighbourhoods (Khartoum (2) (1950), El Diem (1953), and Alamarat (1958)). The research problem is that some of these areas are typically single-use residential areas, with small undeveloped open spaces and poor landscape design. The research is aiming to study the planning of open spaces in these neighbourhoods; collect, analyse and classify the data to find its impact on the development of open spaces. Then set guidelines to achieve well-used open spaces that can best serve the general public. The research was concerned with recognition of good practices that lead to sustainable development of open areas and promoting measurable development indicators such as index of sufficiency, accessibility, safety of the users and social-inclusion dimensions. The analysis focuses on some physical parameters of open spaces e.g. area, fencing, green coverage and types of facilities available (lighting), and some behavioural parameters i.e. type of activities, group of users, developers and managers of open spaces. The results confirmed a lack of a comprehensive development programs and reliable statistics for open spaces that leads to poor variety of outdoor activities. The research found that most of the successful examples of developed open areas of the surveyed neighbourhoods are managed by community groups (public participation).

**Keywords:** sustainable planning, neighbourhoods', open spaces, measurable indicators, out-door activities.

## Introduction

Open space is the publicly owned land that is set aside primarily for recreation, nature conservation, passive outdoor enjoyment and public gatherings. This includes public parks, gardens, reserves, waterways, publicly owned forecourts and squares. Joan Clos (2016) in the foreword of "the city at eye level" said: *"The character of a city is defined by its streets and public spaces. From squares and boulevards to neighbourhood gardens and children playgrounds, public space frames city image"*.

Green areas are very important as sustainable drainage system, solar temperature moderator, source of cooling corridors, wind shelter and wildlife habitat (UN Habitat 2015) . Green areas can reduce noise pollution and the visual intrusion from traffic. The risk of flooding is lower where there is plenty of urban vegetation to intercept and absorb storm water. Urban green areas provide a diverse habitat for many common bird and animal species. There is no comprehensive assessment of challenges or factors behind deteriorating condition of urban green spaces in Africa (Mensah 2014), he gave examples of how high rates of urban sprawl and informal settlements destroying green vegetation in Africa e.g. Reduction in green vegetation from 21% to 12.9% in Abuja due to urban sprawl. The proportion of green spaces appears to decrease in relation to the proportion of residential areas and the proportion of forest, which means that urbanization negatively affects the quantity of urban green spaces, whereas the existence of natural green spaces such as a forest may be seen as a substitute for urban green spaces (Baycan and Nijkamp 2007).

A recent critical review research on green space and quality of life conducted by Green Space Scotland (2008) revealed that physical exercise in green spaces is generally positively associated with promoting well-being and recovery from stress. Also, green space plays a



role in providing places for social interaction and there is some evidence that green spaces do actually promote social cohesion amongst and between different groups in different places, such as parks and gardens. Moreover, individuals who have some nearby vegetation or live closer to green space seem to be more effective in managing major life issues, coping with poverty and performing better in cognitive tasks.

At present, society seems to be polarized. At one extreme are older, more affluent, better educated, more environmentally aware people, who are often the most active users of the countryside and green spaces. At the other extreme are younger age groups, ethnic minorities, who are often much less engaged. These groups have very different values and attitudes. But most people need to access and enjoy different types of landscape at different times and for different purposes (Swanwick 2009). The neighborhoods we live in shape our behaviors and influence our health in other important ways hence, the physical, social and service environments of neighborhoods can promote health or put health in jeopardy (The commission to build healthier America 2008).

Access to, use of and engagement in green space in neighbourhoods can contribute to people's levels of satisfaction and sense of community (Jennings et al 2016).

There are also other positive social uses of open space such as bring people together, build stronger communities and contribute to a healthier society. One of the proposed targets of the United Nations (2016) Goal 11 of the SDG, is *"by 2030, provide universal access to safe, inclusive and accessible, green and public spaces, particularly for women and children, older persons and persons with disabilities"* beneath this target, are specific metrics, called **indicators**, by which progress of the target can be measured and tracked. Measuring public space is not easy, there has been a debate at the Stockholm conference —on what to measure and how to measure it (You 2015). The indicator **now under consideration by the U. N. Statistical Commission** is a quantitative one that would specify the area of public space in proportion to a city's total space. However, there are some parameters that can be considered such as: the safety of women, the elderly and children be ensured in public spaces and the social-inclusion dimension. From 1980–2000, total recorded crime rates in the world increased by about 30% and it is estimated that about 15% of those crimes have a public space design and management component (The Habitat global report on human settlements 2007).

### **Selected Case Studies**

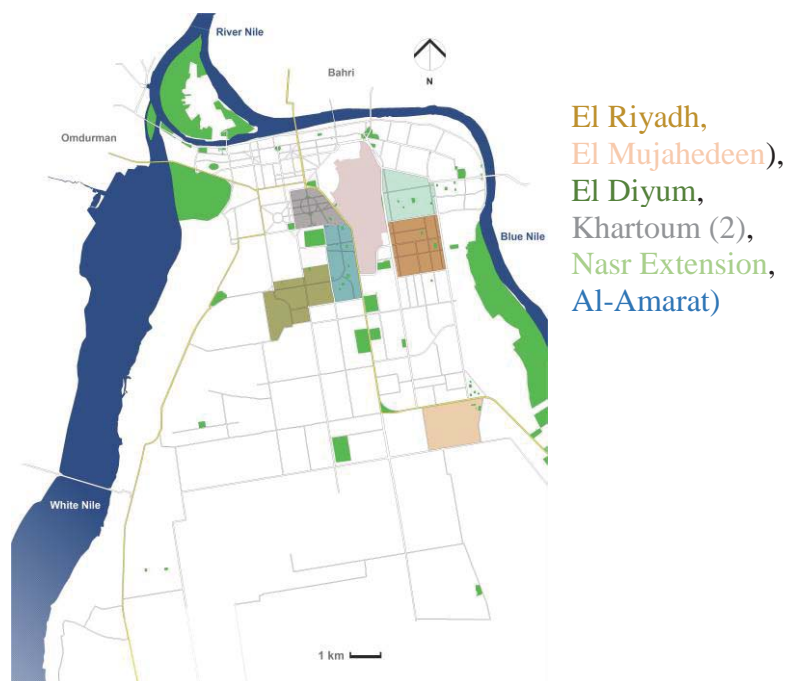
**Khartoum town**, together with the two cities, Omdurman and Khartoum North, constitute the National Capital of the republic of Sudan. It forms a huge triangle. Its population has grown to over 5 million people. The climate is mainly hot desert climate, with an average temperature of 38 C in summer (it may exceed 45C° especially in May), and 24 C in winter, and the total rainfall in autumn is 167 mm. The relative humidity may sometime be low as 20 percent. The unpleasantness of heat during the summer is worsening by the occurrence of dust-storms. Protection from hot dry winds and dust storms is the main target for planners and designers in this climate. open spaces in Khartoum state have been classified into four main classes based on parameters of number of population served and zone of service see table ( 1) below.

Table (1) Classification of open spaces in Khartoum (source: Alhuseen 2015).

Open space	No. of population	Service zone (m <sup>2</sup> )
Neighbourhood court	500-5000	300-500
Residential garden	10,000-20,000	2,000-5,000
Communal garden	20,000-50,000	2,000-5,000
City park	100,000-150,000	Bigger than that

Sudan is classified by the United Nations as one of the Least Developed Countries; low levels of economic development reflected in neglecting public spaces so that most of neighbourhood's open areas are undeveloped for a long time. Lack of development of neighbourhoods' open spaces and thus non-use for these areas make it mostly converted to another purpose like dumpsite or places to gather homeless. Lately, the government began to takes these spaces, and sold them as residential land. Thus, some neighbourhoods in Khartoum town lose totally or partially their open spaces. For this reason, the residents began to develop their neighbourhoods' open spaces to prevent government authorities from violating it, and to improve the quality of their neighbourhoods.

The research was performed in six neighbourhoods in Khartoum Town- First class residential areas: Khartoum (2) and El Mujahedeen, second class residential areas: El Riyadh and Al-Amarat and third class residential areas: El Diyum and Nasr Extension. Location of these neighbourhoods is shown in fig (1) below.



**Fig (1) Location plan of the selected neighborhoods**  
(source: Khartoum Structure Plan 2012)

The research has two methodological phases: (1) a comparison between neighbourhoods by criteria (geospatial data) describing their physical characteristics and (2) a behaviour observation (user-perception surveys). The research has followed qualitative and quantitative methods which included: analysis of documents, photo documentation, observation, and statistical data.

## Discussion

**Planning Pattern:** Neighbourhood open space can take several sizes, shapes, and purposes relative to the class of the residential area. Residential areas have three distinctive classes; first, second and third. the open spaces have hierarchy according to hierarchy of housing cluster, they range from semi-communal open spaces within plots of houses up to communal open spaces which serves larger group of houses. The hierarchy (semi-communal and communal) does not exist in all neighbourhoods. Old neighbourhoods have hierarchy of open space e.g. Al-Diyum neighbourhood, each plot of houses should have direct access to the semi-communal open space (see fig (2)). While new neighbourhoods have non-hierarchical open spaces e.g. Al-Mujahdeen Neighbourhood (fig (3)).



Figure (2) hierarchy of open spaces in Al-Diyum Neighbourhood (source: Google Map 2016)



Figure (3) non-hierarchical open spaces in Al-Mujahdeen Neighbourhood (source: Google Map 2016)

The total No. of open spaces in the selected neighbourhoods is 187 with total area of 558,699 m<sup>2</sup> while the total No. of the developed open spaces is 35 with total area of 154,050m<sup>2</sup> which represent only 27,6 % of the total area as shown in Table (2).

Table (2) Open spaces in the selected neighbourhoods (source: the researcher)

Neighbourhood	Residential class	Area (m <sup>2</sup> )	Inhabitants (person)	No. of open spaces + area (m <sup>2</sup> )	index of sufficiency	developed open spaces + Area (m <sup>2</sup> )	developed open spaces %
1. Khartoum (2)	First	1,457,870	4,871	13 41,850	8.9	6 27,490	65.7
2. Al-Mujahdeen	First	900,000	5552	12 18,800	3.9	4 6400	34.0
3. Al-Riyadh	First+ second	2,774,538	12,797	31 107,000	8.7	3 15,800	14.8
4. Al-Amarat	second	2,050,160	8,184	31 38,120	4.7	8 21960	57.6
5. Al-Diyum	third	2,562,896	29,616	65 226,609	7.7	8 48400	21.4
6. Naser Extension	third	2,214,515	22205	35 126,320	5.7	6 34000	27.0

The percentage of developed open spaces is higher in first and second class residential neighbourhoods e. g. Khartoum (2) (65%) and Al-Amarat (57.6%) than third class residential neighbourhoods Naser Extension (27 %) and Al-Diyum (21,4%) as shown in figure (4). In these neighbourhoods' inhabitants are affluent and can afford spending some money to develop their open spaces.

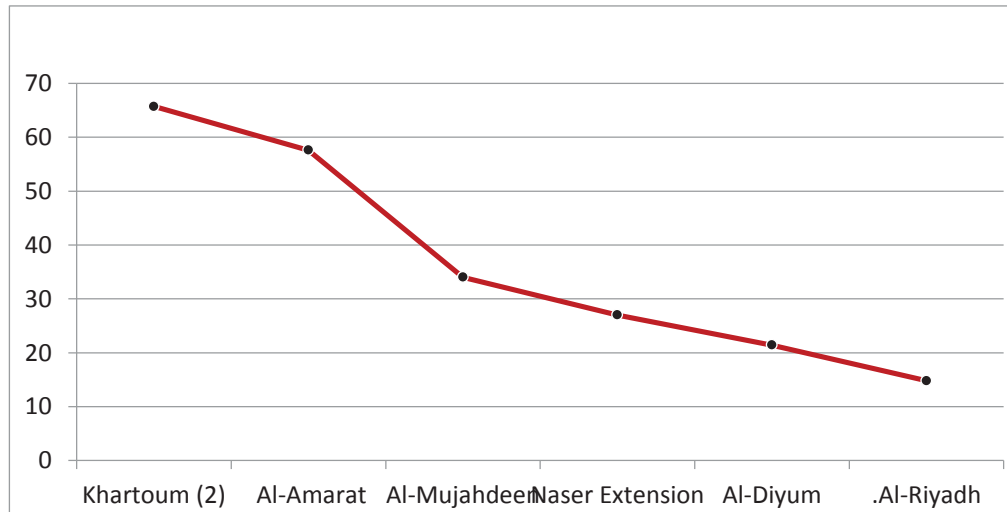


Figure (4) Percentage of the developed open spaces in the selected Neighbourhoods (source: the researcher)

**Functions:** User-perception surveys revealed that developed open spaces within the selected neighbourhoods differ in functions. Each community has variety of activities that can be performed in open spaces. It's clear that the most activities and occasions occurs in outdoor spaces are: children playing, sports, social adults gathering, wedding parties, mourning the dead and eating in Ramadan. Developed open spaces can be categories upon their use to four groups:



1.Outdoor Recreation: Neighbourhood garden that contains recreational facilities, active playgrounds and gardens with sittings e.g. a garden in Al-Amarat (see figure (5)).



Figure (5) Neighborhood garden in Al-Amarat (source: the researcher)

2. Aesthetic Purposes: Green open spaces developed and managed by non-profit organizations aiming to serve the community and improve the aesthetic of the neighbourhood, not containing seating or recreational tools, such as spaces that created by splitting of streets e.g. Badr Park- Khartoum2 (see figure (6)).



Figure (6) Badr Park- Khartoum2 (source: the researcher)

3. Gated open spaces: Green open spaces developed and managed by individuals and in some cases also owned by individuals. Some developers think that, the use of these spaces by the public makes it deteriorate, hence the running cost of development and maintenance is very expensive. So that some developers prevented public to use them and others allow public to access, walking through and taking photos, but there are no places for sitting or playing e.g. Dr.Nabil Rafael Garden (see figure (7))



Figure (7) Dr.Nabil Rafae lGarden (source :the researcher)



4. Community Centres or neighbourhood clubs: Developed open spaces are used as "community centres" which contain recreational facilities according to the needs of the inhabitants, who always participate in its development. These facilities include: - Sports fields, Lounge to watch TV, Commercial activities (restaurant, coffee shop). some of them contain kindergartens and evening classes for school students'. Al-Diyum community centre (see Figure (8)).



Figure (8) Kindergartens in a part of the community centre (source: the researcher)

#### Indicators of sustainable development of open areas in neighbourhoods:

**Index of sufficiency of open spaces:** The index of sufficiency of open spaces is the fraction of the square meters of open space by the number of the neighbourhood inhabitants. The research found that old neighbourhoods e.g. Khartoum (2) (8.9) and Al-Diyum (7.7) have higher index of sufficiency of open spaces than new Neighbourhoods e.g. Naser Extension (5.7) and Al-Mujahdeen (3.9) see table (2) and figure (9) This indicates that planning approaches in 1970s were aware of the importance of providing sufficient open spaces in neighbourhoods.

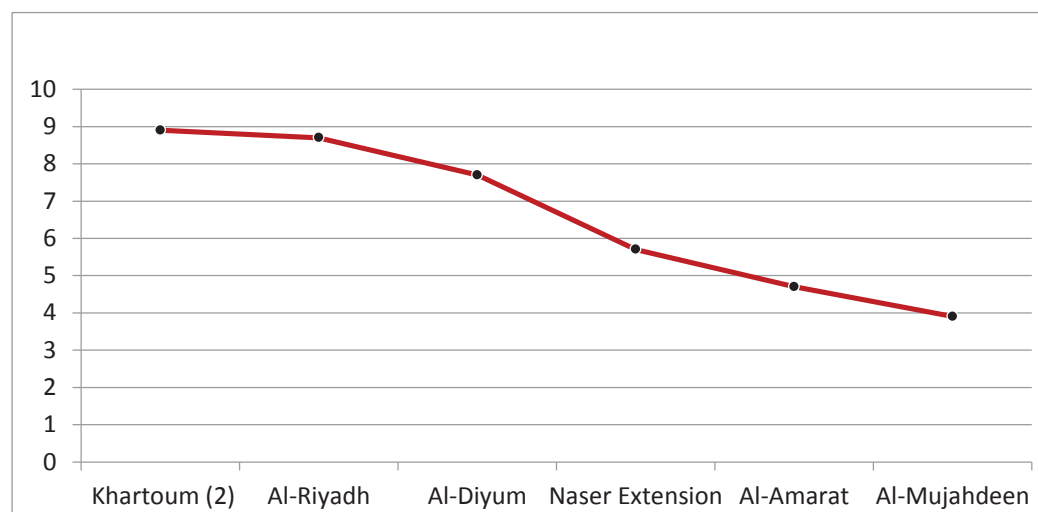


Figure (9) Index of sufficiency of open spaces in the selected neighbourhoods (source: the researcher)

**Social-inclusion dimension:** Unfortunately, most of the developed open spaces are fenced (see table (3)) which indicate a growing tendency of green space being locked behind walls and preventing the public from using them and enhance the social inclusion dimension.

**Accessibility:** the accessibility of developed open spaces is related to the number of these areas and their distribution within neighbourhoods. They are obviously randomly distributed within the neighbourhoods so that some of them have good accessibility ranging

from 122m – 500 m e.g. Khartoum (2), Al-Amarat and Al-Mujahdeen (they are first and second class residential areas) and others have bad accessibility ranging from 565m -1075m e.g. Al-Diyum , Naser Extension and Al-Riyad ( they are-except Al-Riyad- third class residential areas) .

**Safety of women and children:** most of these developed open spaces have lighting (see table (3)) , which to some extent guarantee the safety of women, elderly and children walking by or using these areas.

**Public Participation:** Generally, neighbourhood open spaces in Khartoum town are owned by local government authority, in some cases they are privately owned. The privately owned open spaces are usually developed and managed privately by landowners.

In the selected case-studied most developed open spaces are developed and managed by community groups and individuals at their own expense, sometimes have assistance from the town local authorities (localities) as shown in table (3).

The Factors contribute to sustainable management of neighborhood open spaces are :

- A well organized community group with access to resources and services.
- A local person who acts as a leader who can gain support from several City agencies.
- Clear security for the space, usually in the form of fencing.
- Adaptability of the space to the interests of different age groups of users.

Table (3) indicators of developed open spaces in the selected neighborhoods  
(source: the researcher)

Neighbour - hood	Develo ped open spaces	Area (m <sup>2</sup> )	Green cover -age %	fence	developer	manager	lighting	Accessi bility (m)
1. Khartoum 2	1.1	6,000	50	available	Community group	Community group	available	290
	1.2	9,000	60	-	Private person	Private person	available	122
	1.3	6,000	10	-	Community group	Community group	-	500
	1.4	1200	90	available	Community group	Community group	available	200
	1.5	1200	70	available	Community group	Community group	available	130
	1.6	5600	85	-	Community group	Community group	available	134
2. Al- Amarat	2.1.	3,960	80	available	Private	Private	available	344
	2.2	2,500	50	available	Community group	Community group	available	198
	2.3	2,200	100	available	Private person	Private person	available	434
	2.4	5,200	70	available	Local authority	Community group	available	241
	2.5	2,200	90	-	Community group	Community group	available	418
	2.6	1,800	95	available	Community group	Community group	available	425

	2.7	2,900	40	available	Local authority	Community group	available	375
	2.8	1,200	50	-	Local authority	Community group	-	588
3. Al-Diyum	3.1	9,000	90	available	Local authority	Local authority	available	344
	3.2	9,600	20	available	Local authority	Local authority	available	565
	3.3	1200	95	available	Non-profit organization	Non-profit organization	available	125
	3.4	12,500	50	available	Local authority	Local authority	available	600
	3.5	12,500	10	available	Local authority	Local authority	available	850
	3.6	1200	90	available	Community group	Community group	available	145
	3.7	1200	80	available	Community group	Community group	available	150
	3.8	1200	30	available	Community group	Community group	-	154
4. Naser Extension	4.1	1,600	88.5	available	Local authority	Local authority	available	245
	4.2	1,900	98	available	Local authority	Community group	available	371
	4.3	2,800	70	available	Community group	Community group	available	458
	4.4	7.700	25	available	Private person	Private person	available	582
	4.5	10.000	90	-	Community group	Community group	available	187
	4.6	10,000	5	available	Local authority	Local authority	available	447
5. Al-Riyad	5.1.	2,400	74	available	Community group	Community group	available	300
	5.2	3,000	80	available	Local authority	Community group	available	830
	5.3.	10,400	40	available	Local authority	Community group	available	1075
6. Al-Mujahdeen	6.1	1600	90	-	private	Community group	available	385
	6.2	1,600	40	-	Community group	Community group	available	350
	6.3	1600	80	available	Community group	Community group	-	300
	6.4	1600	60	-	Community group	Community group	-	478

## Conclusion

The absence of a comprehensive development programs for open spaces leads to poor outdoor environments in the selected neighbourhoods. Well designed and well managed open spaces can be used for play, recreation, and relaxation they can also encourage neighbourhood's residents to involve in out-door activities which enhance social interaction and sense of community. The provision of open spaces in Neighbourhoods near to where people live can impact significantly on how places are perceived and are valued locally. The results confirmed differences between the physical characteristics of developed open spaces of the selected neighbourhoods.

The research promoted a set of indicators to evaluate sustainable development of open areas in neighbourhoods such as: index of sufficiency of open spaces, social-inclusion dimension, accessibility, safety of women and children and public participation.

The research found that most of the successful examples of developed open space of the surveyed neighbourhoods managed by community groups (public participation). Some landlords follow different approach e.g. development of commercial activities such as cafes within open spaces to meet user needs and to add attraction to the open space and thus the neighbourhood. The revenue used for maintenance and re-developed of the open spaces.

The research confirmed that public participation and control of open spaces in the design and management process both real and symbolic improve the people's satisfaction with community open spaces.

The survey also disclosed a strong influence of a set of socio-economic variables such as education and economic status on development of open spaces by public participation, the comparison between high income - first class neighbourhoods (Khartoum 2, El Mujahedeen) and low income -third class neighbourhoods (El Diem, Nasr Extension) found that urban open space in the first-class neighbourhoods had more services (e.g. tables, toilets) than open spaces in third class neighbourhoods.

It was clear that accessibility of developed open spaces in first and second-class neighbourhoods are better than third class neighbourhoods.

### **Recommendations**

- Prepare a comprehensive development programs for open spaces in all neighbourhoods with specific action programs.
- Involve the community in the design phases of open space to stimulate creative thinking and generate interest and ownership. Engage people in designing and constructing artworks to improve local environments.
- Encourage inhabitants to improve their open spaces because this can impact significantly on how these places are perceived and are valued locally. Give special attention to neighbourhoods where public participation is weak and not effective.
- Invite developers to invest in part of open space by providing cafes or restaurants and use the revenue to develop the rest of the area.
- public authorities have to take the necessary regulatory measures to counteract a growing trend of green space being locked behind the walls of gated communities.

### **References**

Alhuseen,A, (2015), "Sufficiency of Open Public and Green Spaces in Khartoum State-Sudan", IJournals: International Journal of Social Relevance & Concern (IJSRC) ISSN-2347-9698, Vol 3, Issue 5.

Baycan T. Nijkamp,P (2007).Critical success factors in planning and management of urban green spaces in Europe.International Journal of Sustainable Socitey.

Bell S, Hamilton V, Montarzino A, Rothnie H, Travlou Pand Alves S (2008).

Green space Scotland: research report.

KarssenbergmH, Laven,J. Glaser,M & van,M. (2016). The City at Eye Level. Second and extended version. Eburon Academic Publishers. Delft, the Netherlands

[www.eburon.nl](http://www.eburon.nl)

[Jennings,V](#), [Larson,L](#), and [Yun,J](#). (2016),Advancing Sustainability through Urban Green Space: Cultural Ecosystem Services, Equity, and Social Determinants of Health. International Journal of Environmental Research and Public Health. Published online.

Mensah,C.A. (2014) .Nature and challenges of urban green spaces in Africa. Insights from selected African cities. IERM CONVENTION

Swanwick C (2009). Society's attitudes to and preferences for land and landscape. Land Use Policy. Volume 26, Supplement 1, Pages S62-S75.

You,N (2015). Toward a global action plan for public space-Bridging the urban SDG with Habitat III.citisclope.

The commission to build healthier America (2008) Issue Brief3: Neighborhoods And health. Robert Wood Johnson Foundation.

UN---Habitat, (2007), Enhancing Urban Safety and Security .Global Report on Human Settlements .

UN---Habitat, (2015), Habitat III issue papers 11 – Public Space, New York.

United Nations. (n.d.). Sustainable Development Goals SDGs. Retrieved October 2016, from Sustainable Development: [www.sustainabledevelopment.un.org](http://www.sustainabledevelopment.un.org).



# **Towards Regenerative Sustainable Urban Development with Special Reference to the Egyptian Context**

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**Abstract:** In a world with increasing urbanization which is facing severe environmental crises, the search for means to achieve sustainable urban developments is no longer a luxury. The philosophies behind urban sustainability have become well known. It is important to transform these philosophies into practical guidelines for specific localities to accomplish urban sustainability. This paper aims to develop a tailored set of beneficial, practical and measurable guidelines of sustainable urban development. It starts by discussing different means to achieve sustainable urban developments (rating systems, guidelines, policies...etc.). It focuses on the most critical and foundational sustainable urban design guidelines (the new urban agenda NUA, sustainable development goals SDG...etc.) in order to develop sustainable urban design guidelines tailored to fit the culture, economic and environmental conditions of current Egyptian urbanization. The research uses semi-structured interviews and questionnaires to evaluate the importance of the suggested guidelines using quantitative analysis tools and techniques.

**Keywords:** Regenerative urban design, the new urban agenda, urban design guidelines.

## **Introduction**

Sustainability has been the main concern of several organizations and researchers. That led to the development of various rating systems, strategies, agendas and guidelines to measure and achieve sustainability in the built environment. The scope of sustainable constructions need to include both the architecture -buildings & housing- and the urban scale -planning, design and development of cities- (Houghton, 1997). Even though the philosophies behind urban sustainability are global, the means to achieve them vary according to the local context.

Recently the subject of sustainable development has been widely treated in Egypt. The last few years witnessed the rise of the Egyptian green rating system (The Green Pyramid). Also the Egyptian ministry of planning proposed the sustainable development strategy (Egypt vision 2030). Yet the international experiences and researches are valuable to help developing sustainable guidelines appropriate for the Egyptian context. The present article analysis the most critical and foundational sustainable urban design guidelines (the new urban agenda NUA, sustainable development goals SDG and the CDBE 12 green guidelines) in order to develop sustainable urban design guide-line tailored to fit the culture, economic and environmental conditions of current Egyptian urbanization.

## **Different means to achieve sustainability**

In the last few decades researchers have been concerned about sustainability. Several researchers proposed different means to achieve sustainable buildings and urban settings. These means include; rating systems, design guidelines, urban/building codes and policies.

This section discusses two important means to achieve sustainability; rating systems and design guidelines.

### ***Rating systems***

Rating systems measure projects lifecycle –design, construction, and performance- and compare it to a set of requirements. A project fulfilling these requirements is supposed to be environmentally responsible/ sustainable. In 1998 twelve countries founded the world green building council. Among these countries there are four main rating systems: LEED, BREEAM, GREEN STAR, and CASBEE (World Green Building Council, 2008).

The leadership in energy and environmental design (LEED) is used in the United States, Brazil, Canada, and India. The building research establishment environmental assessment method (BREEAM) is used in the United Kingdom. The green star is used in Australia and New Zealand, while the Comprehensive assessment system for building environmental efficiency (CASBEE) is used in Japan (Say et al, 2008).

The culture and geographic locality of the founding countries is reflected in the point system of each of the four ranking systems. However the variations are few to respond to the specific localities across the world. That's why rating systems maybe valuable for measuring and comparing sustainability, but its influence in achieving sustainability is questionable.

### ***Design guidelines***

The criticism of rating systems lead to the rise of other approaches which aims to achieve sustainability in the built environment both on the architecture and urban scale. Among those approaches are; design guidelines, strategies and agendas which focus on raising the awareness about sustainability and encourage different actors (governments, policy makers, and local communities) to adopt sustainability. Several organizations presented valuable agendas, strategies, and guidelines including; the UN Habitat urban agenda, the sustainable development goals and many other strategies and guidelines. The following sections discusses the most critical and foundational sustainable urban design guidelines.

## **Sustainable Development Goals SDG**

In 2015 the United Nations (UN) proposed a set of 17 goals known as Sustainable Development Goals SDG (United Nation, 2014). The 17 goals builds upon the results of the Rio de Janeiro conference held in Brazil on 2012 (United Nations, 2012). The SDG include 169 targets under them and represent broad goals as; end world poverty, end hunger...etc. (see figure 1). (United Nations, 2015).



Figure 1: SDG, adopted from: United Nations, 2015.

## The New Urban Agenda NUA

The UN habitat presented their New Urban Agenda (NUA) in October 2016. The NUA proposes 35 fundamental elements grouped under five categories: 1-National urban policies, 2-urban legislation, rules and regulations, 3-Urban planning and design, 4-Urban economy and municipal finance, and 5-Local implementation. The NUA aims to provide a framework for local and international cities' development policies (United Nations, 2016)

## The CDBE 12 Green Guidelines

The China Development Bank Capital's (CDBC) developed The CDE 12 green guidelines in 2015 to act as a foundation of sustainable urban developments. The 12 guidelines fall under three categories: Urban form, transportation, and energy and resources (see table 1). (CC Huang, et al, 2015).

Table 1: Categories and elements of the 12 green guidelines.

The CDBE 12 Green Guidelines	
Urban Form	1-Urban Growth Boundary
	2-Transit Oriented
	3-Mixed Use
	4-Small Blocks
	5-Public Green Space
Transportation	6-Non-Motorized Transit
	7-Public Transit
	8-Car Control
Energy and Resources	9-Green Buildings
	10-Renewable and Distributed Energy
	11-Waste Management
	12-Water Efficiency

## Guidelines for Egyptian Urbanism

Conferences like the Rio summit, UN Habitat I, II, and III, and other international gatherings introduced the concept of sustainability of urban developments in many of the third world countries (United Nations, 2012, 2015, & 2016). Among the concerns of such gatherings is convincing different actors –governments, stakeholders, NGOs...etc. - of the importance of constructing healthy cities that preserve the environment through the balancing of using natural resources and development. However most of urban developments in the developing and third world countries demonstrates that sustainable developments are still not a priority. . (United Nations (UN-HABITAT), 2004).

Two of the most important attempts to achieve sustainability in Egypt relies in the development of an Egyptian green rating system (The Green Pyramid Rating System) & the Sustainable Development Strategy (Egypt vision 2030)

### ***The Green Pyramid Rating System (GPRS)***

In 2009 Egypt took a great step towards the research and implementation of sustainable developments through the establishment of the Egyptian Green Building Council (Egypt-GBC). The Egypt-GBC developed –and lately approved- an Egyptian green rating system known as the Green Pyramid Rating System (GPRS). The GRPS use techniques and methodologies

adopted from other rating systems from several countries –USA, Asia, Europe, South America,...etc.- (GPRS, 2011).

### ***Sustainable Development Strategy (Egypt Vision 2030)***

In 2015 the Sustainable development Strategy (Egypt Vision 2030) was proposed during the conference of support and development of the Egyptian Economy. Egypt Vision 2030 proposes a developmental plan based adopting the sustainable concepts developed in the 2030 agenda (United Nations, 2015). It was developed putting in mind the current challenges facing the development process in Egypt. The Strategy includes three dimensions with ten pillars included under them (Ministry of Planning, 2015):

#### *Economic*

The economic dimension comprises the pillars of economic development, energy, innovation, scientific research, and transparency and efficiency of institutions.

#### *Social dimension*

The social dimension involves the pillars of social justice, education and training, health, and culture.

#### *Environmental dimension*

The environmental dimension includes the pillars of environment and urban development.

This paper suggests to utilize the CDBE 12 green guidelines as a mean to achieve sustainable urban developments in Egypt. The reason behind choosing to focus on the CDBE 12 green guidelines lies in the fact that they present one of the most important attempts to set beneficial, practical and measurable guidelines. As mentioned before the CDBE 12 green guidelines are divided under three main categories: Urban form (5elements), transportation (3elements), and energy and resources (4elements). The current study proposed another element under the urban form category: Street Dynamics, making them a total of 13 guidelines.

This section investigates the links between the 13 guidelines (the CDBE guidelines + the proposed element), the NUA, the SDG & Egypt's vision 2030. Table 2 presents the description of each element of the CDBE 12 green guidelines, lead actors and links to NUA, SDG, and SDS. It is worth noting that the numbers listed in table 2 refers to 35 NUA elements, 17 sustainable design goals, and the 30 pillars of the Sustainable Development Strategy that are linked to the 13 guidelines (United Nations, 2015&2016 & Ministry of Planning, 2015) .

Table 2. The 13 guidelines to sustainable developments and their links to the NUA, SDG, and SDS.

	Element	Description	Links to NUA	Links to SDG	Links to SDS.
Urban Form	Urban growth boundary	The ecology and land use of each city should be analysed to establish an urban growth boundary. This boundary should be enforced with exception only due to the lack of infill areas.	1.1, 1.2, 2.1, 2.4, 2.9, 3.2, 3.6, 5.1	10	2, 11, 15, 17
	Transit Oriented	Cities should be transit oriented, where transit systems are within 500-800m. Also it should provide pleasant	1.2	9, 10	11

		walking services within 500m to transit systems.			
	Mixed use	At least six kinds of services should be within 500m to all units. Cities should have a commuting districts bounded for pedestrians and $\leq 15\text{km}^2$ . It should also have a suitable resident-job ration (0.7-0.5)	1.2, 3.4, 3.8, 4.4, 5.5	1, 10	11, 12, 8
	Small block	At least 70% of the blocks –except industrial blocks-should be $\leq 2$ hectares.	1.1, 1.2, 2.4, 3.5	10	11
	Public green space	Public green space –accessible and usable within 500m for all residents-represents 20-40% of the construction areas.	1.2, 2.2, 2.3, 2.9, 3.2, 3.3, 3.5	9, 10	3, 11, 15
	Street dynamics	Enforce the laws regarding the built up area, the plot proportion, floor space, and buildings’ height to ensure achieving appropriate service distribution and street dynamics.	2.4, 2.7, 2.8, 2.9, 3.4, 3.8, 4.5	10	3, 11
Transportation	Non-motorised transit	Encourage non-motorized transit in urban areas through providing connecting walking and biking paths - each $\text{km}^2$ should have at least 10km path-.	1.1, 1.4, 2.3, 3.1, 3.5	6, 9, 10	3, 11, 13, 17
	Public transportation	90% of developments should be within an 800m radius of a public transportation system.	1.1, 1.4, 3.1	5, 9, 10	11, 13, 17
	Car Control	Minimize car use through providing adequate public transportation, encourage non-motorized transit and limit parking.	1.1, 2.9, 3.1	2, 9, 10	11, 13, 17
Energy & Resources	Green buildings	In any development 70% of buildings should earn the Silver Pyramid, 20-40% of buildings should earn the Golden Pyramid, and 5-15% of buildings should earn Green Pyramid –or any other well-known green rating system-.	1.4, 2.7, 2.9, 3.6	2, 9	3, 7, 11, 13, 17
	Renewable energy	In residential areas 5-15% of the energy used should be renewable, and 2.5% for commercial projects.	2.9, 3.6	9	7, 11, 13, 17
	Waste management	Provide waste classification facilities in each project. Encourage waste compost ion (30-50% of waste) and recycling (35-50%).	2.9	9	3, 11, 13



	Water efficiency	All appliances should be water saving. Water used in green spaces should be recycled –rain or waste water-.	2.9, 3.6	9	6, 11, 17
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The current study aims to investigate the usability and applicability of such guidelines in the Egyptian context.

## Methods

In order to develop sustainable urban design guidelines tailored to fit the culture, economic and environmental conditions of current Egyptian urbanization, the current study focused on the most critical and foundational sustainable urban design guidelines (the new urban agenda NUA, sustainable development goals SDG...etc. The analysis of such guidelines lead to the decision to use the 13 guidelines (The CDBE 12 green guidelines + street dynamics) as a mean to achieve sustainable urban developments in Egypt.

To evaluate the importance of the 13 guidelines, the study used semi-structured interviews with architects and experts -working both in academia and the field of practice in Egypt-. The sample included 30 subject. The study used the maximal variation and the snowball sampling procedure to include experts with different backgrounds who may have different opinion and evaluation. The interviewed experts have minimum of five years of experience –either as academics or architects- and work in the field of urban sustainability in the Egyptian context. The interviews focused on measuring three main aspects for each proposed element: importance of this element in achieving urban sustainability, whether is it adaptive/ suitable to the Egyptian context, and if is it applicable.

## Results

The results showed that the Energy& resources was viewed as the most important category –for achieving sustainable development in Egypt- followed by urban form, then transportation. This makes perfect sense as energy is a pressing issue in Egypt, which make it a priority for any sustainable guidelines for the Egyptian context.

As for the evaluation of urban form and transportation, the results show that they achieved almost the same results both in their importance in achieving sustainability and their applicability in Egypt. The only difference is in their adaptability to the Egyptian context, where urban form scored slightly higher than transportation as shown in figure 2.

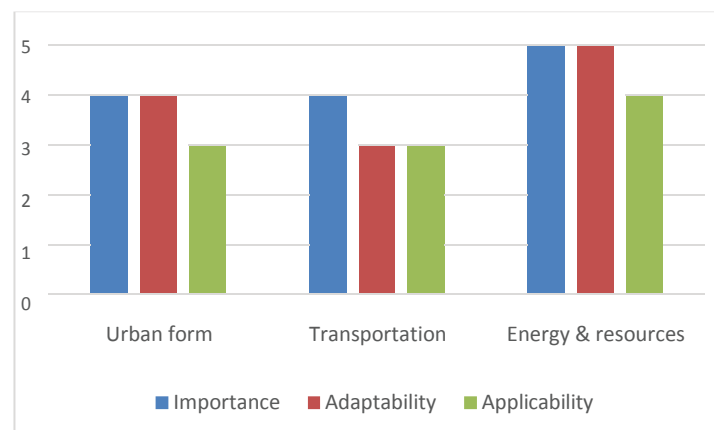


Figure 2. Evaluating the three categories (Urban Form) - (Transportation) - Energy & Resources).

For category one (Urban form): mixed use was viewed as the most important, most adaptive and applicable element to achieve sustainability in the Egyptian context. Urban growth boundary and public green space were also viewed as important factors in achieving sustainability in Egypt (with a score 5/5). Transit oriented and street dynamics followed the previous elements with an average score of 4/5 in their importance. Concerning their adaptability to the Egyptian context, mixed use achieved the highest results (5/5) followed by urban growth boundary, transit oriented, public green space, and street dynamics (4/5). Public green space and street dynamics were viewed as applicable to the Egyptian context (they scored 4/5 and 3/5), while urban growth and transit oriented were viewed as less applicable with an average score of 2/5. Small block was the element to achieve the lowest results on the three aspects: importance (3/5), adaptability (3/5), and applicability (2/5) as shown in figure3.

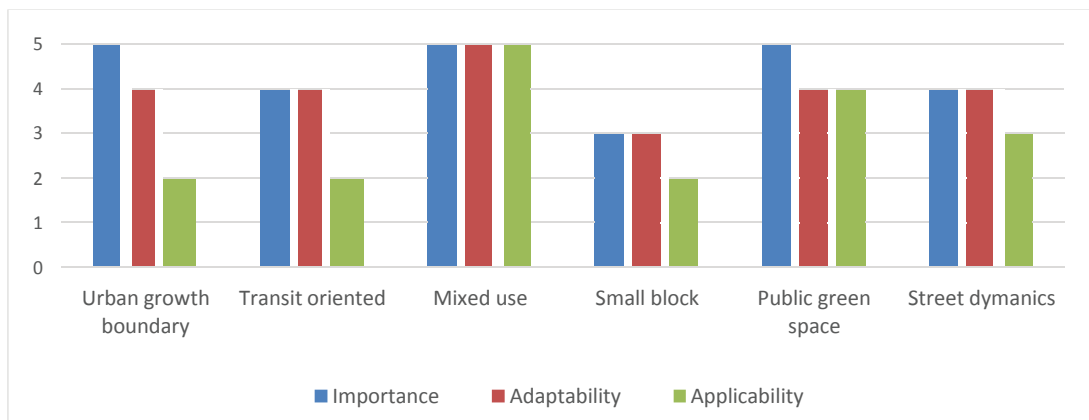


Figure 3. Urban form results.

Category two (Transportation) results show that public transportation is the most important element in achieving sustainability in Egypt (with a score 5/5), followed by non-motorized transit and car control (both scored 4/5). Regarding their adaptability and applicability to the Egyptian context public transportation was also found the most adaptive element (with a score of 5/5) followed by car control with relatively lower score (3/5). They were both reported as applicable with an average score of 4/5. Even though non-motorized transit was reported as an important element it achieved very low results (1/5) both in its adaptability and applicability to the Egyptian context (see figure 4).

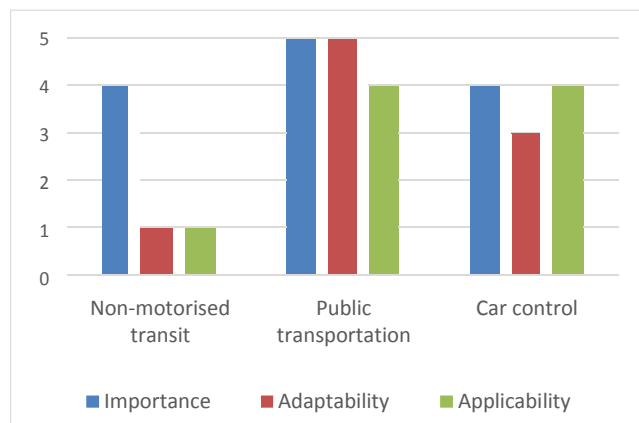


Figure 4. Transportation results.

Category three (Energy & resources) results show that most the elements (renewable energy, waste management, and water efficiency) were reported as important in achieving sustainability (with an average score of 5/5). Green buildings was also reported as an important element with slightly lower results (average score of 4/5). Renewable energy was reported as the most adaptive element to the Egyptian context (with an average score of 5/5), followed by waste management with a score of 4/5, then water efficiency (with an average score of 3/5). Green buildings was reported as the least adaptable and applicable element with as average score of only 2/5. Waste management was reported as the most applicable element (with an average score of 4/5), followed by renewable energy and water efficiency (both scored 3/5) as shown in figure 5.

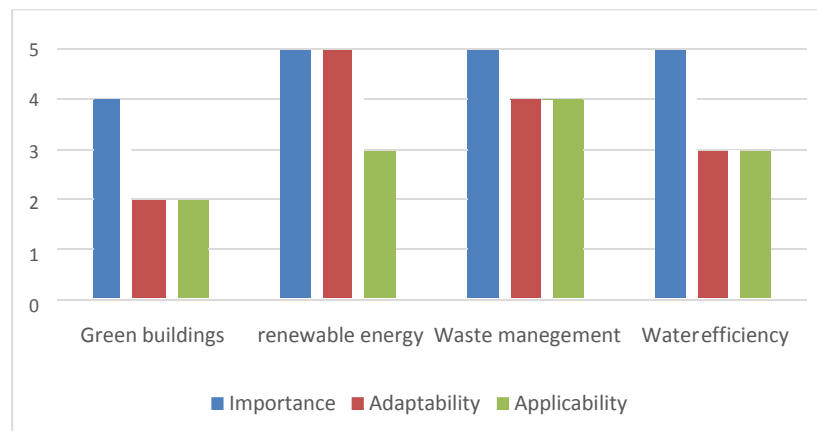


Figure 5 Energy and resources results.

## Discussions and Recommendations

Interviewing academics and professionals working in the Egyptian context resulted in recommending the use of the proposed guidelines for achieving urban sustainability in Egypt. Even though the three categories are important yet (Energy & Resources) is viewed to be the most important category to the current Egyptian context. The current study suggests working on increasing the public awareness -especially the construction field and investors- on the importance of following the qualifications of green rating systems. Also there is a need to provide the adequate training to the workers—both in construction and maintenance- to cope with the new techniques and building materials.

The second category (transportation) plays a significant role in achieving sustainability yet many challenges stands in the way of attaining it. For instance encouraging non-motorised transit –walking and cycling- can reduce the use of energy, pollution, traffic, and increase health of residents. However culture issues and security concerns reduces the applicability of non-motorised transit in Egypt. Also the design of new Egyptian cities/settlements doesn't respect the pedestrian movement.

Regarding the first category (Urban form) the current policies and regulations in the Egyptian codes complies with most of the proposed elements. Two main problems are facing the realization of these elements. First: application of the law. Several violations of these laws happen which needs seriousness in the regulation, application and subjecting accountability towards any violations. The second problem lies in maintenance. For instance when green public spaces are provided, the lack of maintenance leads to the deterioration of such spaces.

## Conclusions

Green rating systems played an essential role in raising public awareness about sustainability. They evaluate how green a building is, but that doesn't represent a reliable and precise measurement of the impact of this building on the environment. Being international systems with low consideration of specific localities raises a question about the end result which led to the search for other means to achieve urban sustainability.

Several international organizations provided valuable strategies, vision and goals for achieving urban sustainability. However most of these frameworks provide various important goals and targets but are not clear on how and by whom they can be supported and fulfilled in each locality. Thus the relevance of these propositions to governments and dwellers – especially of developed third world countries- determines their significant. It has to respond to the billions of people who live in conditions that don't meet their basic needs. That's why the 12 green guidelines represent a valuable approach as it focused on the application of beneficial, practical and measurable elements. Interviewing Egyptian academics and practitioners showed that the proposed green guidelines are mostly adaptive and applicable in the Egyptian context. Still further researches need to be done to physically test the application of such elements in the design and implementation of urban developments in Egypt.

The sustainable development goals are already developed we need to focus more on how to implement them. Also the issue of actors and funding must be addressed. The role of local democracies that encourage citizens to participate in the execution of sustainable visions and strategies is another pressing issue that need to be addressed in our Egyptian locality.

## References

- Candace Say, A. W., 2008. Sustainable Rating Systems Around the World. *Council on Tall Buildings and Urban Habitat CTBUH*, Issue II.
- CC Huang, et al, 2015. 12 Green Guidelines: CDBC's Green and Smart Urban Development Guidelines, China: China Development Bank Capital (CDBC).
- GPRS, 2011. *Green Pyramid Rating System for Public Review*, Egypt: Egypt green Building Council. Housing and Building national ResearchCenter.
- Haughton, G., 1997. Developing sustainable urban development models. *Cities*, 14(4), pp. 189-195.
- Ministry of Planning, 2015. *sustainable Development Strategy : Egypt's Vision 2030*, Cairo, Egypt: Ministry of Planning, Monitoring and Administrative Reform.
- United Nation, 2014. Press release - UN General Assembly's Open Working Group proposes sustainable development goals", Retrieved 2016-10-18.: [Sustainabledevelopment.un.org](http://Sustainabledevelopment.un.org).
- United Nations (UN-HABITAT), 2004. The state of the world's cities 2004/2005: globalisation and urban culture, Nairobi/London: UN-HABITAT/Earthscan.
- United Nations, 2012. *The Future we Want*, Rio de Janeiro, Brazil: Rio+20 United Nations Conference on Sustainable Developments.
- United Nations, 2015. Transforming our world: The 2030 Agenda for Sustainable Development, s.l.: United Nations.
- United Nations, 2016. *New Urban Agenda*, Quito, Ecuador: United Nations Conference on Housing and Sustainable Development (Habitat III).
- World Green Building Council, 2008. *World Green Building Council*, s.l.: s.n.

# Urban Livability Dimensions in the Egyptian New Cities. Case study: Sheikh Zayed city.

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**Abstract:** Livability is a concept that has been experienced worldwide. There is no standardized definition of livability, it is equivalent to the quality of living in a city and is determined by various dimensions. It is a tool to measure sustainability in many cities over the world.

The term livability is an umbrella to a variety of meanings, which depend both on the objects of measurement and on the perspective of those making those measurements. This paper explores the inter-relationship between livability and urban design, focusing on the socio-cultural dimensions. It starts by reviewing the most significant urban dimensions presented in literature worldwide. This paper aims to analyse the city livability to suggest a set of urban dimensions to achieve livability in the Egyptian new cities. It measures urban livability at different urban contexts in Sheikh Zayed city in Egypt, reviews residents' perceptions of Sheikh Zayed city. The research uses a quantitative tool (schema ball) to identify the relationship between different urban livability dimensions in the Egyptian new cities.

The analysis shows the similarities and diversities of urban livability dimensions in the Egyptian context and discusses the problems most relevant to people's lives at the moment and to propose the possible steps we can take in future to turn Sheikh Zayed city into a more livable city.

**Keywords:** Livability, Sheikh Zayed city, urban Dimensions, schema ball.

## Introduction

What makes a city or a community liveable? This question has no fixed or single answer, In a Country as large as Egypt with such a wide range of urban context with different themes, livability is best defined at the local level.

Livability includes broad human needs ranging from food and Basic security to beauty, cultural expression, and a sense of belonging to a community or a place. Livability is a perceived experience by people who live, work, or recreate in particular places, People and place are the two sides of livability, but livability indicators often refer only to locality or territory, rather than to individuals.

Various researchers as Pacione has relied on residents experiences as a measurement of city planning quality because the human-built topography of city greatly impacts residents' social and psychological wellbeing (Pacione, M.2003). Thus, the residential environment has become one of the most important factors that affect consumer choice and property selection (Visser et al., 2005).

Because of the wide geographical area in an urban setting, a residential environment that is able to satisfy the daily demand of inhabitants is desired. Therefore, it is crucial for urban planners and cities administrators to be involved in the things that are important to



people that allow them to live satisfying lives. There is a growing awareness of the deterioration of livability, particularly in urban environments because of the pressure of rapid development and a growing population.

Most researchers have reported livability as a concept that is difficult to define and measure (Wheeler, 2001; Balsas, 2004; Heylen, 2006). The term livability is an umbrella to a variety of meanings, which depend both on the objects of measurement and on the perspective of those making those measurements.

Heylen (2006) revealed that there has been no agreement in the literature concerning the dimensions that should be incorporated to capture the concept. Such discrepancy in views is common because researchers differ in their background discipline. Thus, livability is used in several studies, ranging from different scales of residents, neighbourhood and country to multiple disciplines, such as ecology, geography, sociology and urban planning.

Many studies use different dimensions to measure livability in different urban context in different countries as Leby and Hashim (2010) who measure it in Malaysia, and many reports for specific places as The American Institute of Architects 2005, "Place, Health and Livability Research Program"(2013).

Thus, it is the aim of this study to recognize the attributes and the dimensions that residents consider in evaluating the livability of their city, Therefore, it is essential for urban planners and cities administrators especially in Egypt to be interested in the things that are important to people that allow them to live satisfying lives, this paper help them to improve the livability in the Egyptian new cities and measure the most effective dimensions in the eyes of the new Egyptian cities residents, as Egypt is in the 121 rank according to The Economist Intelligence Unit Limited 2015.

### **Understanding Livability**

Livability is an ensemble concept whose factors include or relate to a number of other complex characteristics or states, including sustainability, quality of both life and place, and healthy communities (Norris and Pittman, 2000; Blassingame, 1998), It is the most immediate appearance of sustainability that, like livability, refers to the ability of a place or a community to meet the needs of its citizens without compromising the ability of future generations to meet their full range of human requirements.

And it's also defined as "A behaviour-related function of the interaction between environmental characteristics and personal characteristics" (Pacione, 1990).Wheeler's (2001) define livability as the quality of being pleasant, safe, affordable and supportive of the human community.

Although the definition of livability varies from community to community, a given community's goals can be approached, and community planning for livability can be achieved, using community-derived indicators. Often, the initial goal for people involved in the planning process is to determine what is important in and to the community.

"Livability reflects the wellbeing of a community and comprises the many characteristics that make a location a place where people want to live now and in the future" (Victorian Competition and Efficiency Commission, 2008).

However, livability has been defined in other ways, such as "a statement of desires related to the contentment with life in a particular location..." (De Chazal, 2010).

Where definitions are explicitly stated, livability is given a diverse range of meanings, with no standardized definition or theoretical framework employed in the literature.

## Livability dimensions:

There is a wide range of factors that augment a community and make it a desirable place to live. The dimensions of livability are multiple and complex, including not only the built environment but also social, economic and natural factors. They vary somewhat across cities and cultures and certainly are not absolute. (Southworth, 2016)

Livability has a number of key dimensions. Importantly, most definitions align livability with local community wellbeing. Livability also appears to be primarily concerned with the physical attributes of a particular location. However, the literature indicates that livability is not just inherent in environmental characteristics. Rather, it is a function of the relationship between the environment and the social life it sustains (Hankins, 2009), (Pacione, 1990), (Dorst, 2010). This suggests that there is a social dimension to livability, concerning how people interact within local environments (Wheeler, 2003).

Basic dimensions of livability are not completely separable or mutually compensatory. Livability concepts often treat economic, environmental and social factors as separate domains that can be traded against each other.

A few examples among many alternatives include economic indicators, such as whether jobs pay living wages, come with health insurance and retirement benefits, are close to affordable transit and child care, and provide safe working environments. Social indicators might include community involvement, number of community gardens, distance between residences of extended family members, access to health care, and equity (diversity, employment types, etc. (Community and Quality of Life, 2002)

Examples of place-based environmental indicators include measures of species diversity, soil type, land use, surface water, wetlands, and so forth. Transportation indicators include data on the percentage of the population commuting a particular distance, the percentage using public transit versus personal vehicles, and alternatively.

The key is to realize balance among social, environmental, and economic indicators and to attend to the interrelationships among these all indicators. The range of possible indicators is wide, but a balanced set will include indicators from the social, environmental, and economic sectors.

Basic dimensions of livability are not totally separable or mutually compensatory. Livability concepts often treat social, economic, and environmental factors as separate domains that can be traded against each other.

Table1: summary of livability dimensions

Omuta(1988)	Employment, Housing, Amenity, Educational, Nuisance , Socio-Economic
Holt-Jensen(2001)	Aesthetics Of Living, Environment, Personal, Social Relations, Functional.
Visser et al(2005)	Housing, Social Environment, Physical Environment, Functional
AIA (2005)	A Sense Of Place Mixed-Use Development- Density- Transportation- Street-Savvy Design- Physical Health And Community Design- Public Safety, Personal Security.
Heylen(2006)	Dwelling-Social Environment- Physical Environment- Safety.
ODPM(2006)	Environmental Quality- Physical Environment- Functional Environment- Safety.
Lowe et al(2013)	Housing- Employment And Income- Social Cohesion And Local

	Democracy- Crime And Safety- Education- Transport- Public Open Space- Health And Social Services.
Paasch,2015	Comfort- Access- Function- Maintenance- Sociability.

A glance at the various studies found that several livability dimensions, such as functional, physical and social environments, are selected in all cases, which reflects people's common understanding of living environment.

From the analysis of the previous dimensions, we propose six dimensions of urban, economic, social, environmental, safety and transportation with 23 sub variables, see table 2, we choose these dimensions because they were the most mentioned in literature and most relevant to the Egyptian context. It should be noted that these dimensions might not have precisely the same content and meaning as those used in other literature, even though the same term might be used.

Table2: The chosen livability dimensions.

Livability dimension		theme
Urban	V1	Housing affordability.
	V2	Streets quality
	V3	Open spaces and sense of place.
	V4	Street scape.
	V5	Density
	V6	Mixed use and services
Social Dimensions	V7	behaviour of neighbours
	V8	community life and social contact
	V9	the sense of belonging
Economic Dimensions	V10	Income.
	V11	Employment opportunities.
	V12	Employment varieties
Safety Dimension	V13	number of crime
	V14	the feeling of safety
	V15	lighting
	V16	fire fighting
	V17	security
Environmental Dimensions	V18	Air pollution
	V19	Water pollution
	V20	Sound pollution
	V21	Visual disturbance
Transportation	V22	Means of transportation
	V23	signs

## **Methodology**

### ***Population and Sampling Plan***

This study was undertaken in Sheikh Zayed City, one of the new cities in Egypt, The target theoretical population of this study is comprised of residents who are lived in gated communities and others who live in open communities.

A multistage sampling method was adopted in which several rounds of cluster sampling were carried out prior to establishing the accessible population, the whole population was subdivided into clusters according to their kind of living community and random samples were then collected from each group.

### ***Survey Instrument***

The questions were formulated using a quantitative scale with which respondents were asked to express the importance of indicators.

Apart from this, the questionnaire also contained demographic questions that included the respondent's age, gender, income, household income, education level, employment status, tenure status and length of residency in the city.

Among them, open-ended questions were used to gauge information on respondent's age, income, household income, length of residency and number of family members. The results obtained were re-coded into various categories to facilitate statistical analysis as shown in table 4.

### ***Data Collection Method***

Before the questionnaires were distributed to the subjects, a pilot test was carried out. A pilot study with ten respondents was conducted to test the workability and communicability of the questions. Changes to the survey were minimal and involved clarifying unclear items by inserting parenthetical examples and omitting some questions.

Results were analysed by using SPSS software to get correlation matrix between different variables then forms a schema ball to Visualization the matrix into a simple way to explore the relationship between different variables to indicate which variable is active on and which is passive on the perception of livability within the local residents.

The activity of a variable is the row sum of all the impacts that is variable has on all other variables, (i.e., the extent to which a variable's impact on other variables is active).while passivity: the sensitivity/passivity of a variable is calculated by summing up the cells of the column  $i$ , that is, the impacts that all of the other variables have on it.

### **Sheikh Zayed city planning.**

The Egyptian New Communities (ENC) development started in the second half of the nineteen seventies and continued in varied-paces till the present.

Sheikh Zayed is one of the ENC, ENC were frequently located outside the traditionally populated area away from the limited agricultural land corridor, and it is one of the new communities adjacent to the boundary of greater Cairo, established in 1995. (Abdel Kader et al, 2013).

The city is located out of the ring road west of great Cairo to accommodate the increase in the population of greater Cairo and to control the informal expansion on agricultural land. The city is physically attached to six October City in a distinguished area.



According to new urban communities authority (NUCA) in Egypt, The total number of housing units is 84335, 16918 implemented by New Urban Communities Authority and 1601 Dar Masr project, 16240 unit by ministry of housing, 40696 unit implemented by private sector. Current Population is 293 thousand inhabitants, and the target is 675 thousand inhabitants. (NUCA, 2017).

The city's urban mass consists of 17 districts, which was planned to accommodate the low and middle income inhabitants. Some districts are totally developed, and the rest are gradually developing according to the situation of plot subdivisions to be built by the owner, there is more than 14 gated communities vary in area between 1500 to 6500 acres as Beverly hills to 20 to 100 acres like the address compound.

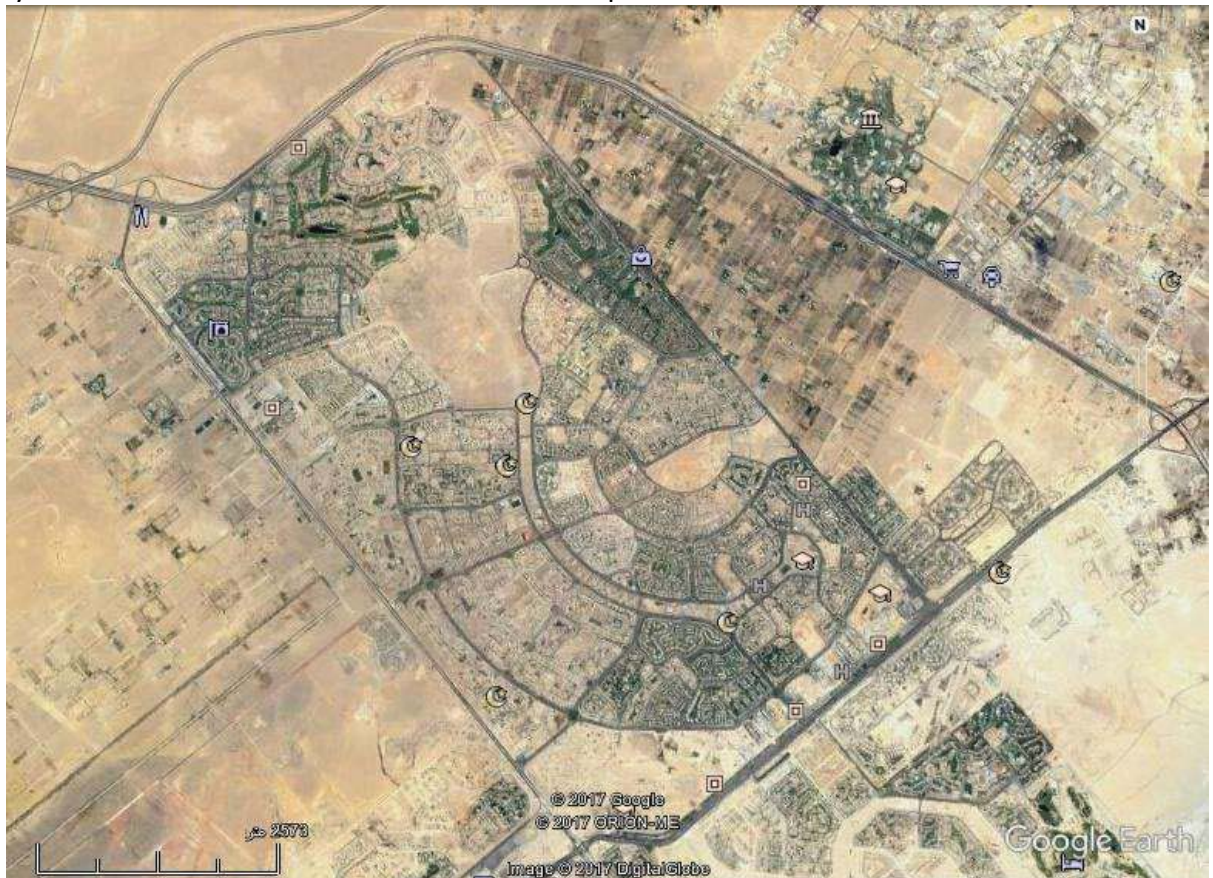


Figure: 1 Sheikh Zayed city planning - Google earth 2017

## Results and Discussion

From August 2017 to September 2017, a total of 40 questionnaires were completed, the sample was composed of 38% male and 62% female respondents. Their age varied between 30 to 40 years old. Most the respondents are living in Sheikh Zayed for more than 5 years (55%). Nearly 56% of the respondents had a monthly personal income more than LE 10000 (567 \$).

This paper represents a cognitive evaluation of the residents on different city issues associated with residential living environment. The results of this study provided an understanding of resident's perceptions of different variables which are active or passive on recognizing livability that was shown by schema ball figure3.

We observed that the importance of different livability dimensions, differ by the change of residential environment. Residents in open communities reported that security



and safety is the most important dimension to realize the livability while for residents in gated communities reported that environmental dimension is the most important in Sheikh Zayed city as shown in table 3.

Table 3: cross tabulation between residential environment and livability dimensions.

Livability dimensions	residential environment	
	open communities	gated communities
safety dimensions	9	3
urban dimensions	4	3
environmental dimensions	1	5
transportation dimensions	1	4
economic dimensions	3	1
social dimensions	2	1

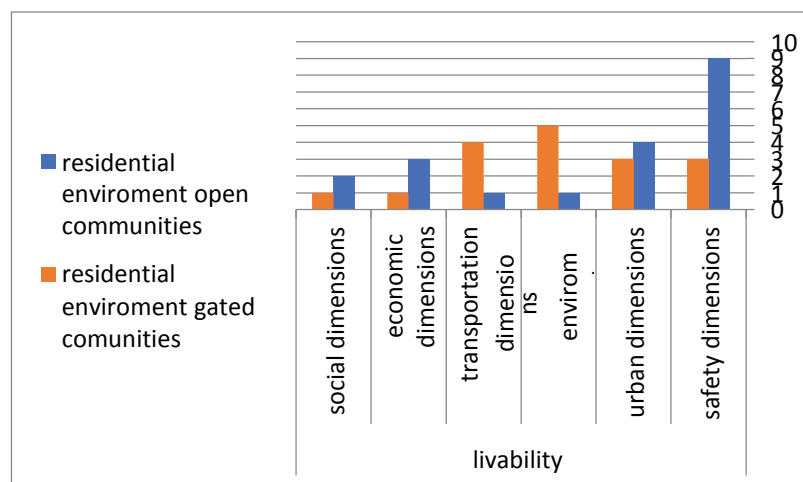


Figure2: cross tabulation between livability dimensions and type of residential environment

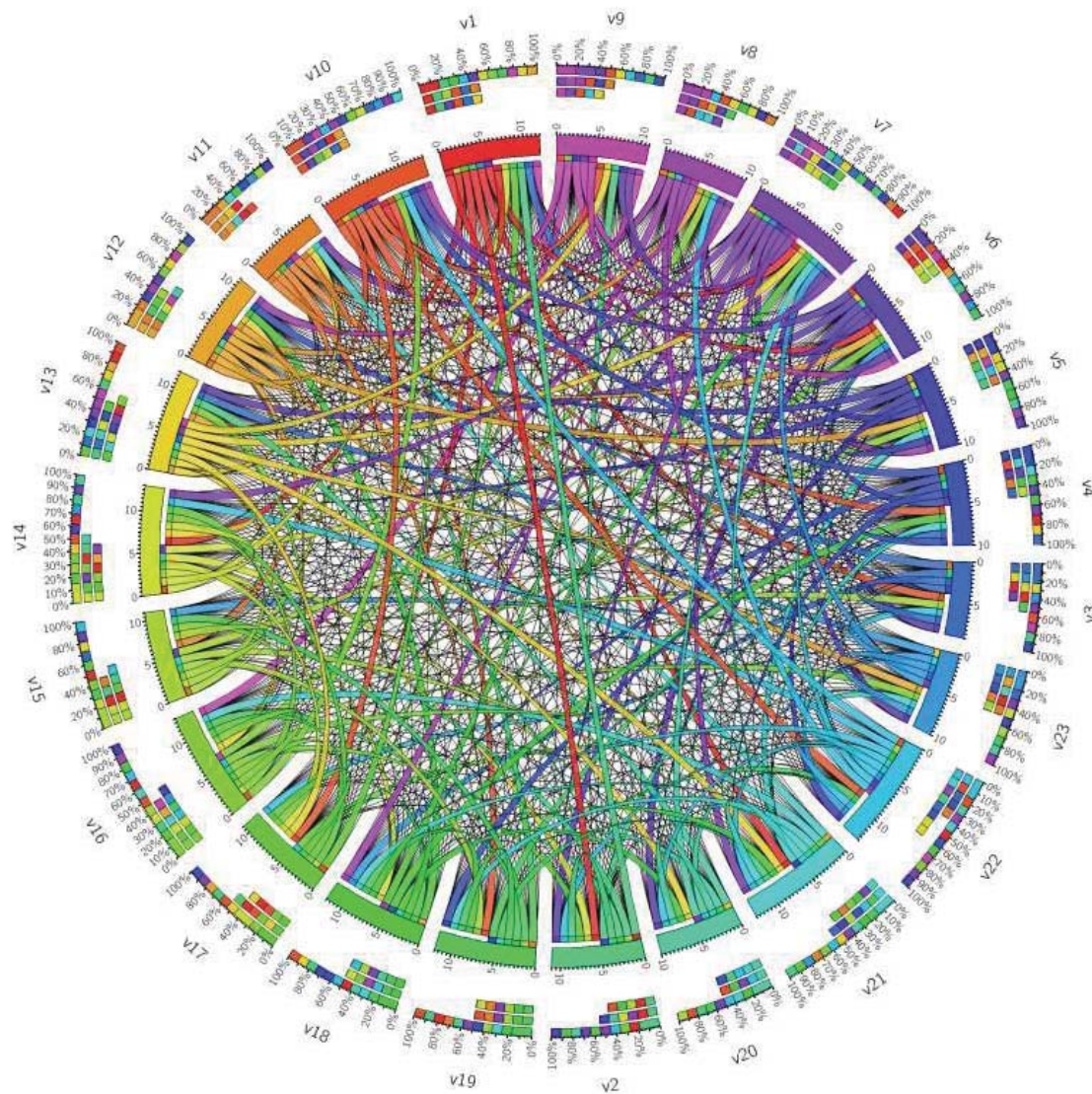


Figure 3: Schema ball between the 23 variable.  
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Table 4: schema ball analysis and results

Domain	Active variable		Passive variables		Discussion
urban	Vv1	Housing compatibility.	V3	Open spaces and sense of place.	The ability of the housing unit to fulfil the residents' requirements and needs .increases the perception of livability within the local residents. However, the variable of the sense of place is considered as passive variable due to it affected by the other variables as Streets quality and Street scape.

Domain	Active variable		Passive variables		Discussion
social	Vv7	of behaviour neighbours	V8	community life and social contact	Neighbours' behaviour and attitudes affects greatly on the feeling of livability within the studying area, while, any disturbance in the other variables effect on social connections and community contact due to its sensitivity to sense of belonging.
economic	Vv10	Income.	V11	Employment opportunities.	The income is an important variable that affects economic value of livability, on the other hand Employment opportunities is very sensitive that affected by the economic dimension as Employment varieties
safety dimension	Vv14	feeling of safety	V17	security	Feeling safety is an active variable that defines Livability value, any enhancement within safety feelings increases the achievement of livability domain. Security is very sensitive variable, that affected by all safety dimension variables.
Environmental dimensions	Vv21	Visual disturbance	V20	Sound pollution	The active variable that affects both the environmental dimension and the livability is the visual disturbance, due to lack of maintenance, and un-used spaces, while sound pollution is affected by other variables due to inappropriate land-use and activities.
transportation	Vv22	Means of transportation	v23	signs	The two variables of transportation domain affects livability, where means of transportation acts as active variable, while the signs and street labels is sensitive variable that affected by transportation and accordingly livability.

## Conclusion

Livability is an umbrella to a variety of meanings, it differs from place to another, it is related to a number of other complex states or characteristics, including sustainability, quality of both place and life, and healthy communities.

The findings of this study have provided a better understanding of the issues of livability especially in the Egyptian new cities as Sheikh Zayed, An understanding of the term

requests to be approached from the perspective of the residents. Knowledge of the subjective, human side to livability can shed light on the situation outside objective indicators so that policymakers and planners are better informed of residents' satisfaction and what they really need.

Correlation matrix then schema ball showed the active and passive variable in each dimension. The analysis indicated that efforts to promote city livability should focus on ensuring the overall feeling of safety in open community because this tends to increase their satisfaction level. The perception of crime and feeling of safety are greatly influenced by the way a neighbourhood is managed, maintained, lighting efficiency, street network design and the presence of security all these elements increase the resident feeling of safety, security is very sensitive variable, that affected by all safety dimension variables.

Street networks should be designed with a relatively continuous building frontage to create interest for pedestrians and provide passive surveillance to improve security and increasing lighting efficiency in them.

While residents of gated communities stated that environmental dimension was the most important to realize livability. They focus more attention on the availability and the quality of parks and open green spaces, and they care to be out of any kind of pollution.

This study provides evidence that urban policymakers should also direct their efforts to policies that promote livability dimensions in the Egyptian new cities.

In brief, the liveability of cities is a crucial element to the prosperity and development of cities because it reflects the real-life experiences of inhabitants. Thus, a liveable environment creates an optimistic future for quality and living comfort, which ultimately become the determining factors in creating a sustainable built-up environment of the whole.

City livability against gated communities is one of the most important fields that can be studied in future especially in Zayed city as it contains a lot of gated communities.

## References

- Abdel-Kader, N.; Ettouney, S., (2013) *Rethinking New Communities Development - with Reference to Egypt's 40 Years' Experience*" 39th World Congress on Housing Science, Milan..
- The American Institute of Architects (AIA), (2005). *What makes community livable, livability 101*, USA.
- Blassingame, Lurton. (1998). *Sustainable cities: oxymoron, utopia, or inevitability?*. Social Science Journal 35:1-13.
- National Research Council. (2002). *Community and Quality of Life: Data Needs for Informed Decision Making*. Washington, DC: The National Academies Press. <https://doi.org/10.17226/10262>
- De Chazal, J., (2010). *A systems approach to livability and sustainability: Defining terms and mapping relationships to link desires with ecological opportunities and constraints*. Systems Research and Behavioural Science, 27(5): p. 585-597.
- Hankins, K.B. and E.M. Powers. (2009). *The disappearance of the state from 'livable' urban spaces*. Antipode, 41(5): p. 845-866.
- Leby, J. and Hashim, A., (2010). *Livability Dimensions and Attributes: Their Relative Importance in the Eyes of Neighbourhood Residents*, Journal of Construction in Developing Countries, Vol. 15(1), 67-91.
- Lowe, M., Whitzman, C., Badland, H., Davern, M., Hes, D., Aye, L., Butterworth, I. and Giles-Corti, B., (2013) *Liveable, healthy, sustainable: What are the key indicators for Melbourne neighbourhoods?*, Research Paper 1, Place, Health and Livability Research

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[http://mccaugheycentre.unimelb.edu.au/research/health\\_and\\_livability](http://mccaugheycentre.unimelb.edu.au/research/health_and_livability)

Southworth, M..(2016) *Learning to make liveable cities*, Journal of Urban Design, 21:5, 570-573, DOI: 10.1080/13574809.2016.1220152

New urban communities' authority. (NUCA) in Egypt.  
[http://www.newcities.gov.eg/know\\_cities/Sheikh\\_Zayed/default.aspx](http://www.newcities.gov.eg/know_cities/Sheikh_Zayed/default.aspx)

Norris, Tyler, and Pittman, M., (2000). *The health communities movement and the coalition for healthier cities and communities*. Public Health Reports 115:118-124.

Pacione, M. (1990), *Urban livability: A review*. Urban Geography.11(1): p. 1-30.

Pacione, M. (2003). *Urban environment quality and human wellbeing-A social geographical perspective*. Landscape and Urban Planning, 65 (1-2):19-30.

van Dorst, M.(2010), *Sustainable livability: Privacy zoning as a physical condition for social sustainability, in Environment, health, and sustainable development*, A. Abdel-Hadi, M. Tolba, and S. Soliman, Editors., Hogrefe Publishing: Cambridge, MA. p. 111-125.

Victorian Competition and Efficiency Commission, (2008), *A state of livability: An enquiry into enhancing Victoria's livability*, Final report, Victorian Competition and Efficiency Commission: Melbourne, Victoria.

Visser, P., van Dam, F. and Hooimeijer, P.,(2005).*The influence of neighbourhood characteristics on geographical differences in house prices in the Netherlands*. Paper presented at European Network for Housing Research (ENHR) International Housing Conference, 29 June-3 July 2005, Reykjavik, Iceland.

Wheeler, S.,(2003). *Planning sustainable and livable cities, in The city reader*, R. LeGates and F. Stout, Editors., Routledge: London and New York.



# Motivating participation in regenerating sustainable urban neighbourhood open spaces

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**Abstract:** Re-generating neighbourhood communities that are physical, socially, and economically sustainable is a major challenge. A “sustainable urban neighbourhood” is a small-scale urban area within a city that comprises economic, social and environmental sustainability. However, open spaces as a vital component of the neighbourhood’s physical structure, have an important role to play. They represent the arena of both, neighbours’ outdoor interactions, subsequently building the neighbourhood’s sense of community. Several approaches have been implemented to regenerate sustainable urban neighbourhoods’ open spaces. Yet this paper adopts a new approach based on the motivational theory. This approach –based on the motivating potential score MPS- relies on a mathematical formula, which examines the motivation score that reveals the low values which have to be enhanced, and the high values which must be enriched.

This paper aims to investigate the roles of regenerating sustainable urban neighbourhoods in terms of open spaces and gathering areas to enhance the communities’ sustainability. It examines how local partners can work together to raise the sense of locality and realize the aspirations of their needs and concludes with recommendations for better neighbourhoods and stronger communities.

The paper offers the Motivating Potential Score as an integrated tool used to evaluate the capacity to motivate local community participation. MPS model imitates the psychological state of local community partners, motivational characteristics, and personal attributes, which influence response to challenging and complex participation tasks.

Finally, the paper applies its findings to one of the open spaces in Egypt; Cairo ‘masaken Othman’ as an open space re-design. The application comes to show the validity of the conceptual application of the proposed motivating potential score upon encouraging the local community to participate in re-designing their own neighbourhood open spaces, towards the more sustainable urban neighbourhood.

**Keywords:** Sustainable urban neighbourhood, local partners’ participation, Motivation theory, motivating potential score MPS, regenerating urban open spaces.

## Introduction:

It is no longer a doubt that in the last few decades, community participation have finally earned a great attention as a tool towards urban development and social sustainability.

Participation has become a cultural necessity for the local community in re-generating their neighbourhood open spaces, not only for its importance for the urban development physical aspects, but also, for enhancing the non-physical values for the communities’ quality of life. However, it is difficult to achieve sustainable development without local community participation, there for, this paper offers the Motivating Potential Score (MPS) as a tool to motivate the local community to participate, and measure their willingness and capability to involve and engage together to fulfil their urban and social needs.

## Sustainability for better communities

Community sustainability is often defined by the desire to meet today's needs without compromising the quality of life for future generations. It is the process where community members come together to take collective action and generate solutions to their problems.



Figure 1. Sustainability for better communities  
Source: [www.betterbuildingsinitiative.energy.gov](http://www.betterbuildingsinitiative.energy.gov)

Concepts and literature confirmed that sustainable development is a continuous process to change the current situation to a better one urbanely, managerially, socially & economically (Scott et al, 1998). It depends on a comprehensive integrated concept, and the utilization of all potentials and available financial and human resources of the community; in order to achieve a sustainable development to the community, and reach the maximum benefit in the shortest time possible (Ward et al, 2013).

Community sustainability seeks to empower individuals and groups of people with the skills they need to effect change within their communities. These skills are created by forming social groups working for a common goal. That is to be achieved through the community itself, the community which reflects its experiences and cultural values on its urban environment, to fulfill the needs of the present without negatively affecting the needs of the future (Witten, et al 2008).

As communities face increasingly complex problems, making progress toward sustainability requires different and various approaches, although community participation has been an important aspect to achieve sustainability, but it needs motivation theories aiming to achieve continuity in sustainability, make the most efficient use, and enhance the quality of life, and motivate the local community to participate in re-designing their own neighbourhood open spaces (Huston et al, 2003).

### Urban neighbourhood open spaces

The neighbourhood is a basic planning entity in modern residential planning theories, in addition, it is the local environment at one of its most humanly relevant scales (Ward et al, 2013). However open spaces as a vital constituent of the neighbourhood's physical structure, have an important role to play.

They are the arena of the neighbours' outdoor interactions –consequently building the neighbourhood's sense of community - setting its parameters and configuring its fundamentals, because it is as much a perceptual area as a physical one. Neighbourhood open spaces have long been thought to offer a sense of coherence and identity, making urban life more manageable and meaningful (Francis et al, 2012).

There are different approaches that tackle the application of sustainability to neighbourhoods open spaces. Among these approaches, stands both participation and motivation as two integrated perspectives (Scott et al, 1998). Motivating the local community

to participate in redesigning their neighbourhood open spaces is an important approach towards more sustainable community (Gupta et al, 2012).

Participation itself is an aspect that targets sustainability, integrating participation with motivation offers a greater opportunity to achieve continuity in the sustainable development on various levels of urban neighbourhoods' open spaces, and the social community (Huston et al, 2003).

### Community participation

Community participation is an approach to actively involve all stakeholders (e.g. partners, citizens, users) in the re-design process of developing neighbourhood open spaces to help ensure the result meets their needs and is usable (Anuar et al, 2013). It also means enabling community sectors in all development aspects, and benefiting from its financial and human resources in planning and implementing development programs, it is necessary that people contribute in the efforts to improve their living conditions (Witten, et al 2008).

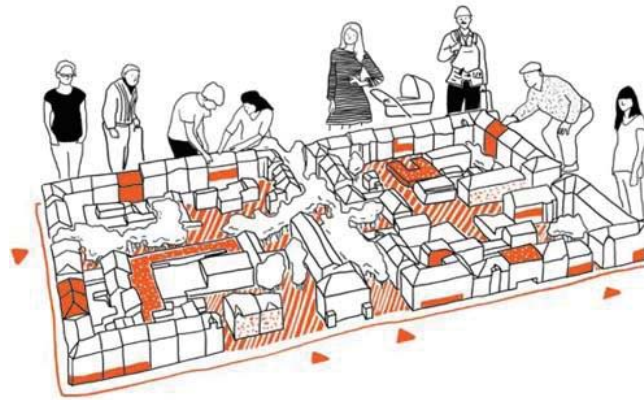


Figure 2. Community participation, discussion and decision making. Source: Overmeyer et al, 2013.

Participatory design is an approach which is focused on processes and procedures as a way of creating environments that are more responsive and appropriate to the local community's cultural, emotional, spiritual and practical needs. It is one approach to Placemaking (Anuar et al, 2013). People need to participate in the process of identifying the needs, setting priorities and execution of activities and projects. Successful participation process depend on discovering and developing those who are leaders by nature (Witten, et al 2008). Those key players hold the direct responsibility of creating initiatives to cause a real change in the local community (Nasution et al, 2012).

Adopting the environmental psychology approaches to encourage local community to participate in re-designing their own neighbourhood open spaces is based on both the social and economic neighbourhood's ability to tackle sustainability issues, applying the techniques of how local partners can work better together to foster localism and realize the aspirations of their needs for better neighbourhood and stronger sustainable communities (Huston et al, 2003).

## Motivation approach

Throughout history, motivation is considered central to individuals and society to perform and participate at any required task or activity. In any society, developed or developing, motivation determines the ways of life and patterns of interactions. It serves as means of nurturing positive feelings and provides better environment. (Hackman et al, 2005).

One of the earliest theories of motivation was developed by the ancient Greek philosopher Aristotle, who postulated that motivation is associated with an ongoing perception process to control outcomes (Steel, 2012).

Starting from 1974, Hackman and Oldham conducted their motivation Survey model as an attempt to make it a measurable assessment tool for task achievement and participation satisfaction (Hackman et al, 1976), this measurable tool consists of a questionnaire of twelve questions and a mathematical formula, the outcomes of the questionnaire is substituted in the formula to obtain a measurable results. Consequently, from that model, they derived a score for motivating the potential of performing or participating in a certain task or activity.

The motivation approach has been developing ever since, in 1986, James and Tetrick established a temporal relationship between task characteristics and participation (Steel, 2012). Based on their assumption, an ample number of theories regarding motivation by Behson, Eddy, and Lorentzet in 2000 and Humphery, Nahrgang, and Morgeson in 2007, Schjoedt raised the level of research to the field of entrepreneurship in 2009 (Oldham et al, 2010).

All those theories addressed the motivation of individuals in a working environment (Steel, 2012), while, in this research, motivation will have a perceptual shift toward motivating local community to participate in urban development programs, to promote community engagement within their surrounding context.

## Motivating potential score

$$\text{Motivating Potential Score (MPS)} = \frac{(\text{Skill Variety} + \text{Task Identity} + \text{Task Significance})}{3} \times \text{Autonomy} \times \text{Feedback}$$

Figure 3. (Equation 1).

Source: Hackman and Oldham (1974).

According to the final version of the theory, five core characteristics should prompt three critical psychological states, which lead to many favourable personal and community outcomes, in addition to the questionnaire of the twelve questions and the mathematical formula, which has been addressed by Hackman and Oldham from 1974 and developed ever since.

When an individual has a high score on the five core characteristics, it is likely to generate three psychological states, which can lead to positive community outcomes, such as high internal local motivation, high satisfaction with the participation terms, high quality engagement performance, and high volunteering opportunities with low absenteeism attitude (Steel, 2012).

This tendency for high levels of motivation lead to positive outcomes can be formulated by the motivating potential score (MPS). The MPS as an index that reflects the ability of a person to achieve certain activity, which indicates his degree of motivation (Hackman et al, 2005). The motivating potential score (MPS) can be calculated, using the core dimensions, as follows:

Table 1. summarizes the conceptuality of each dimension

number	characteristics	Conceptualization
1	<i>Skill Variety</i>	The degree to which a task requires various activities, requiring the participants from the local community to develop certain skills and talents (Humphrey et al, 2007).
2	<i>Task Identity</i>	The degree to which the task or activity requires the participant to identify and complete the whole process with a visible outcome (Pierce et al, 2009). Participants from the local community experience more meaningful participation when they are involved in the entire process rather than just being responsible for a part of it (Steel, 2012).
3	<i>Task Significance</i>	The degree to which the individuals' participation affects other people's lives (Oldham et al, 2010). They feel more meaningful when their participation substantially improves either psychological or physical well-being of others (Pierce et al, 2009).
4	<i>Autonomy</i>	The degree to which participation provides the local community with significant freedom, independence, and discretion to plan out how to perform their engagement and determine the procedures of their involvement. (Humphrey et al, 2007). A high level of autonomy, the outcomes depend on the participants' own efforts, initiatives, and decisions; rather than on the instructions from the authorities or a manual of procedures (Pierce et al, 2009). In such cases, the local community experiences greater personal responsibility for their own successes and failures at their urban context (Steel, 2012).
5	<i>Feedback</i>	The degree to which the local community has knowledge of results (Oldham et al, 2010). This is clear, specific, detailed, <i>actionable</i> information about the effectiveness of his or her performance. When the community receive clear, actionable information about their performance, they have better overall knowledge of the effect of their work activities, and what specific actions they need to take (if any) to improve their participation (Steel, 2012).

Source: Hackman and Oldham (1974).

According to the equation above (figure 3), the value of either autonomy or feedback will substantially compromise the participation's MPS, because autonomy and feedback are the characteristics expected to foster experienced responsibility and knowledge of results, respectively (Oldham et al, 2010). On the contrary, a low score on one of the three characteristics that lead to experienced meaningfulness may not necessarily reduce participation's MPS, because a strong presence of one of those three attributes can offset the absence of the others.

To better assess the local community' participation in developing their urban context, Hackman and Oldham, built and conducted a measurable questionnaire consisting of twelve questions scaled from 0 to 6 (Humphrey et al, 2007), shown as follow:



Table 2: MPS questionnaire

Question		0 very inaccurate	1 mostly inaccurate	2 slightly inaccurate	3 uncertain	4 slightly accurate	5 mostly accurate	6 very accurate
1	Supervisors often let me know how well they think I am performing the job.							
2	The job requires me to use a number of complex or high-level skills							
3	The job is arranged so that I have the chance to do an entire piece of work from beginning to end.							
4	Just doing the work required by the job provides many chances for me to figure out how well I am doing.							
5	The job is not simple and repetitive.							
6	This job is one where a lot of other people can be affected by how well the work gets done.							
7	The job does not deny me the chance to use my personal initiative or judgment in carrying out the work.							
8	The job provides me the chance to completely finish the pieces of work I begin							
9	The job itself provides plenty of clues about whether or not I am performing well.							
10	The job gives me considerable opportunity for independence and freedom in how I do the work.							
11	The job itself is very significant or important in the broader scheme of things.							
12	The supervisors and co-workers on this job almost always give me “feedback” about how well I am doing in my work.							

Source: Humphrey et al, 2007

By completing this questionnaire, it is possible to compute the MPS. This survey provides quantitative measures through the MPS, which is the measure of the overall potential to enhance substantial motivation (Oldham et al, 2010). MPS is equivalent to the product of three factors: The average of the first three core dimensions (skill variety, task identity, and task significance), the autonomy, and the feedback. It can be calculated using the formula above, (figure 3), (Pierce et al, 2009). Using this formula, MPS can record the lowest score value (0.0), when the motivation potential of each dimension is the lowest. While, it can record the highest score value 1728.0, when the motivation of each dimension is the highest (12).

There is a proportionality between the MPS and its characteristics, that is that the maximal score is recorded when all the characteristics are maximized (Humphrey et al, 2007).

### **Methodology of the case study**

Many efforts were done in an attempt to increase communities' levels of substantial motivation to participate in developing their urban context. Based on this perspective, the motivation potential score will be applied on the local community at certain urban setting (Masākin `Uthmān, 6th of Oct. Giza, Egypt.) To calculate and measure their level of motivation to participate in upgrading their neighbourhood open spaces. The case study has been selected based on certain criteria: the project has to be a planned residential area, regenerating the neighbourhood open space has to be based on the participatory approach between the local community and all stockholders (authorities and NGOs, the project outcomes has to fulfil the local community's needs and requirements.

### **Case study background**

The Geneina project, Masākin `Uthmān residential area, 6th of October City, Giza governorate, Egypt. Figure 4. Shows its location in relation to the other areas; the Industrial Zone, al-Ḥuṣary Square, and al-Shaykh Zāyid City.



Figure 4. Masākin `Uthmān's location in relation to the other areas the Industrial Zone, al-Ḥuṣary Square, and al-Shaykh Zāyid City. Source: [www.tadamun.co](http://www.tadamun.co)

#### **Location:**

The Geneina project - Masākin `Uthmān, lies within the borders of al-Giza governorate, yet since it also lies within the borders of a "new city"- 6th of October City, it falls under the jurisdiction of the New Urban Communities Authority, a governmental agency affiliated to the Ministry of Housing, Utilities, and Urban Development.

#### **Project brief:**

New residential area, which has come into being as a result of the program Gamāl Mubārak publicized in 2005 of The National Housing Project, and which is now populated in part by some of the slum residents, whom the Cairo governorate had indeed relocated, as announced in 2010 (ISDF. 2011). The Awla bi-l-Ri`āya "The Most Care-Worthy" housing in 6th of October City, or "Masākin `Uthmān", as it is better known among its residents and the few outsiders who know of it, housing units were to be 42m<sup>2</sup>, eligible citizens, the "Awla bi-l-Ri`āya", are ambiguously defined as "citizens most in need, who would be unable to make down payments – workers in factories located in new cities". The Arab Contractors Company (Osman Ahmed Osman & Co) was one of the companies contracted to build the units (UN-HABITAT 2012). This is partly why the housing development has come to be known among residents and outsiders as "Masākin `Uthmān" [`Uthmān Residences], although its official title is "al-Awla bi-l-Ri`āya".

### *Population:*

Its residents, having come from different areas and countries, have almost nothing in common but their need for affordable housing. Those resettled from areas such as Manshiyāt Nāṣir and `Izbit Khayrallah, and Refugees residing in Masākin `Uthmān come from a number of countries, namely Syria, Sudan, Somalia, Iraq, and Yemen, while, Syrians may plausibly constitute the largest group (ISDF. 2011).

### *Project conditions:*

The uniformly designed blocks – varying only in façade colour – are tightly packed together in groups and separated by wide corridors and sizeable plots. These in-between spaces were intended to serve as community gathering nodes and child-friendly play areas (UN-HABITAT 2012). In reality, some of these spaces suffer from flooded sewage, in addition to household solid waste. These spaces also attract the children in the area, who are often found loitering and playing unattended amidst the garbage heaps and stray dogs, (www.tadamun.co).



Figure 5. Project condition, Rooftop view showing the almost adjacent cemetery. Uniform blocks, endless space, and neglected. Source: www.tadamun.co

Although Masākin `Uthmān has an open layout and is very walkable, the suboptimal use of the aforementioned spaces along with the overwhelming uniformity of the blocks, the emptiness of their surroundings, and the lack of signs and distinguishing characteristics make the place feel dull, uninviting, and a little intimidating (ISDF. 2011).

### *Open spaces renovation: The Geneina*

Due to the neglected open spaces, and the lack of maintenance, the Project was transforming a neglected open space into Geneina ‘garden and playground’ for children, (www.tadamun.co). It was designed and implemented by one of the local non-governmental organization ‘Takween Integrated Community Development’ one of TADAMUN’s partners, in addition to German co-operation (November 2014 – January 2015).



Figure 6. Geneina Open space renovation. Source: www.tadamun.co

'Geneina' in Action: Workshops organized to produce 'Geneina's children play elements , A series of workshops, open to specialists and faculty students, to construct outdoor play elements for the children (ISDF. 2011). These workshops are organized to be part of the process of implementing the project of 'Geneina'; a new public space developed for children of Masaken Othman, ([www.tadamun.co](http://www.tadamun.co)).

A quick impact project to upgrade a public open space in 6th of October City in participation with Syrian refugees and community members, included a series of workshops, funded by German Cooperation and open to specialists and faculty students, to construct outdoor play elements for the children, based on recycled materials (reused tires). These workshops were organized to be integrated into the implementation. (UN-HABITAT 2012).

#### *a. Physical & socio-economic*

'Geneina' is the new open space located in Masaken Othman area (6th of October City), providing a recreational communal node that serves the children and women residing in the area. The area allows the local community (of all ages and nationalities) to actively play. The space is created as an interactive atmosphere with a diversity of playing elements that are designed and based on participatory design workshops conducted with the area's children and adults. It is a place for the children that they can call their own, where they can play freely and enjoy the simplest rights of their childhood (ISDF. 2011). Geneina also targets to provide a platform for mothers -and women in general- to interact openly and safely. Creating an outdoor safe environment, offering a functional public open space, which is highly needed as expressed by the local community of Masaken Othman; aiming to increase the opportunity of integration and mutual acceptance between the local residents, from one side, and from the other side, the refugee community in the area ([www.tadamun.co](http://www.tadamun.co)).



Figure 7. Aerial view to the Geneina project. Source: [www.tadamun.co](http://www.tadamun.co)

#### *b. Participatory design & Implementation*

The primary vision of Geneina's sustainability plan includes different activities such as the construction of a 5v5 football playground, to meet the needs of Masaken Othman's male youth; cultural and artistic activities as well as, a community centre for education and awareness raising ([www.tadamun.co](http://www.tadamun.co)). Two years after the implementation of Geneina "Meet and play" project; Masaken Othman's children learned different cultural and educational activities, as well as public performance skills. Geneina Project Owner and Main Partner: 6th of October City Administration Initiated by: UNHCR Funding Agencies: Kuwait Responds, German Cooperation Concept and Implementation: Takween Integrated Community Development, Make Space for Play. (UN-HABITAT 2012).





Figure 8. local community participation. Source: [www.tadamun.co](http://www.tadamun.co)

### Sampling process – questionnaire application

Sampling is a method of selecting a certain number of residents from a total population. Define the population (n) frame: Target sample should have lived not less than 5 years in the urban setting. Therefore, their age is in a range between (25-50 years old). The sample population has covered both genders but not in equal ratio due to the difficulties to have a large sample of women to interview and ask question in public paths. Determine sample size: Total research sample is 50 of the local residents, with a group of 40 men and 10 women; about 70% of the sample is employed while the other 30 % are seeking for an opportunity to work. About 65% of the sample populations are highly educated, while the 35% haven't completed their years of education. This sample is considered 10% of the total number of residents how participated in redesigning the neighborhood open space (500 participants). And before distributing the questionnaire, a pilot test has been conducted, to study the workability and communicability of the questions, as the MPS is relatively a new methodology approaching the urban participation scope. The results and outcomes can be considered as a scan with a reliable indicators that maybe approached with a long term project to obtain more deep insights with larger sample scale.

### Results and conclusions

After passing the questionnaire over the sample of the local community participants, the numbers came from having average of their answers, and by applying the MPS formula, Results can be classified as following:

Each core characteristic is calculated from the answers of two questions, for example, Skill variety is calculated from the answers of questions no. two and no. five, the answer of question number two was (2.0), and the answer of question number five was (1.0), i.e.(2.0+1.0)=3.0, these numbers came from having average approximated value form the participants' answers.

Task identity: is calculated from the answers of questions no. three and no. eight: (4.0+2.0)=6.0

Task Significance: is calculated from the answers of questions no. six and no. eleven: (6.0+5.0)=11.0

Autonomy: is calculated from the answers of questions no. seven and no. ten: (4.0+1.0) =5.0

Feedback from the task itself: is calculated from the answers of questions no. four and no. nine: (4.0+5.0) =9.0

Feedback from others is calculated from the answers of questions no. one and no. twelve: (3.0+4.0) =7.0. Total feedback (9.0+7.0)/ 2= 8.0

MPS =  $\frac{\text{Skill variety} + \text{Task identity} + \text{Task significance}}{3.0} \times \text{Autonomy} \times \text{Feedback}$

MPS =  $\frac{3.0 + 6.0 + 11.0}{3.0} \times (5.0) \times (8.0) = 266.66$



***Based on this results, the research concludes the following:***

The value of the MPS for the Geneina project, Masākin `Uthmān residential area, 6<sup>th</sup> of October City, appeared to be quite low on the motivation scale  $0.0 < 267.0 < 1728.0$

This value based on the results and outcomes of the questions that indicated the lack of the sustainable motivation of the participants' community, and the continuity of this sustainability.

This was clear from the value of the core characteristic 'task identity' - answers of the third and eighth questions - revealed the absence of the system that allows the participant to follow the activity he is performing from the start to the end. (Ex. the activity of painting and colouring, participants were not part of choosing the colours and the type of drawings that will be applied, they participated in the part of the activity, concerning the drawing and colouring, which affected their performance to have the chance to do an entire piece of work from beginning to end).

The value of the core characteristic 'task significance' calculated slightly high score '(6.0+5.0) =11.0' which indicates the importance of the activity itself and its significance to the broader scheme of the project, the feeling of the participant of how a lot of other people can be affected by how well the work gets done, that has been successfully achieved within the Geneina project. (Ex. The importance of every task even small activities as garbage collection, watering plantations).

Participants of the Geneina project did not get a considerable opportunity for independence and freedom in how they perform certain activity. That was obvious in the value of the core characteristic 'autonomy' that scored '(4.0+1.0) =5.0' due to denying the chance to use their personal initiative or judgment in carrying out and performing their activity, that occurred due to authorities constraints and limitations, which framed their personalization of the space.

Based on these results, this papers offers group of recommendations;

**Recommendations**

Enabling local community to participate in re-designing and reclaim their open space, which means that the main purpose of their participation is not just causing materialistic changes but also moral ones, by focusing on developing the community member's character through motivating them and increase their involvement in the process of causing the required changes to re-design their neighborhood open space.

Motivation process must include the study, discussion, planning, implementation and group evaluation, and engaging the local community in all those stages. Motivating potential score must be applied at the beginning of the development program, it is a tool to measure the willingness of the community to perform certain task, not a post occupancy evaluation tool.

Involving local community in the planning and execution of re-design their neighborhood open space is important to raise their awareness about better life conditions.

Reaching tangible results to the community which depends on a main factor that is earning the community members' trust, and fulfilling their physical needs, and social requirements.

Giving the local community a considerable opportunity to use their personal initiative or judgment in carrying out the activity, with a percentage of independence and freedom.

Ensuring the values of how significant the activity is important and affective in the project's broader theme and in others' lives.

Allowing the local community to have continues feedback about their performance and opportunities for improvements and enhancement.

## REFERENCES

- Anuar, M. I. N. M., & Saruwono, M. (2013). Obstacles of Public Participation in the Design Process of Public Parks. *Journal of Asian Behavioral Studies*, 3(8), 89 – 99.
- Francis, Jacinta; Giles-Corti, Billie; Wood, Lisa; Knuiman, Matthew (2012). "Creating sense of community: The role of public space". *Journal of Environmental Psychology*. 32 (4): 401–409.2012.
- "Geneina project, Takween Integrated Community Development – one of TADAMUN's partners".[www.tadamun.co](http://www.tadamun.co). Retrieved 2017-09-21.
- GOPP, UN-HABITAT, & UNDP. (2012). Urban Development Strategy for Greater Cairo. Part 1: Future Vision and Strategic Directions.
- Gupta, K., Kumar, P., S.K.Pathan, & K.P.Sharma. (2012). Urban Neighborhood Green Index - A measure of green spaces in urban areas. *Landscape and Urban Planning*, 105, 325-335.
- Hackman, J. R. & Oldham, G. R. (2005). How job characteristics theory happened. *The Oxford handbook of management theory: The process of theory development*, 151-170.
- Hackman, J. R. & Oldham, G. R. (1976). *Motivation through the Design of Work: Test of a Theory. Organizational behavior and human performance*.
- Humphrey, S. E., Nahrgang, J. D., & Morgeson, F. P. (2007). Integrating motivational, social, and contextual work design features: A meta-analytic summary and theoretical extension of the work design literature. *Journal of Applied Psychology*, 92(5), 1332.
- Huston SL, Evenson KR, Bors P, Gizlice Z. Neighborhood environment, access to places for activity, and leisure-time. 2003;18(1):58–69
- ISDF. (2011). The Committee's Report on the Service Needs of Residents Resettled from Unsafe Areas to 6<sup>th</sup> of October City.
- Nasution, A. D., & Zahrah, W. (2012). Public Open Space's Contribution to Quality of Life: Does privatisation matters? *Asian Journal of Environment-Behaviour Studies*, 3(9), 59 – 74.
- Oldham, G. R., & Hackman, J. R. (2010). Not what it was and not what it will be: The future of job design research. *Journal of Organizational Behavior*, 31, 463-479.
- Oishi, S., Diener, E. F., & Suh, E. M. (1999). Cross-cultural variations in predictors of life satisfaction: Perspectives from needs and values. *Personality and Social Psychology Bulletin*, 25, 980–990.
- Oakley, I., Chen, M., & Nisi, V. *Motivating Sustainable Behavior*. University of Madeira, Portugal. 2008.
- Pierce, J. L., Jussila, I., & Cummings, A. (2009). Psychological ownership within the job design context: Revision of the job characteristics model. *Journal of Organizational Behavior*, 30(4), 477-496.
- Scott, James C. (1998). *Seeing Like a State: How Certain Schemes to Improve the Human Condition Have Failed*. New Haven and London: Yale University Press.
- Steel, Piers. *Motivation: Theory and Applied*. Boston, MA: Pearson Learning Solutions, 2012. Print. pp. 49.
- "Urban Parks, UCLA Institute of the Environment and Sustainability". [www.environment.ucla.edu](http://www.environment.ucla.edu). Retrieved 2017-08-22.
- "Urban Summit Report (2003) ODPM". [www.urbansummit.gov.uk](http://www.urbansummit.gov.uk). Retrieved 2017-09-11.
- Ward Thompson, Catharine (2013). "Activity, exercise and the planning and design of outdoor spaces". *Journal of Environmental Psychology*. 34: 79–96.
- Witten K, Hiscock R, Pearce J, Blakely T. Neighbourhood access to open spaces and the physical activity of residents: a national study. *Prev Med*. 2008;47(3):299–303.

## Connectivity and place-making

### Blue-green transects: prospective potentialities towards social sustainability

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**Abstract:** Isolation becomes a phenomenon that defines the contemporary Cairene urban fabric seen, on the one hand, in the massive implementation of gated communities, and on the other hand, in the forms of imposed siege surrounding informal settlements. A particular urban topology composed of the network of the irrigation and drainage water canals of the former agriculture land located in the intersection between the rural and urban limits could be a mean to struggle against this phenomenon. Thus, our aim is to rethink an intelligent transformation of these blue-green courses as an agent of “connectivity” on spatial and social levels. Proposing a conceptual framework pursuing “connectivity” will be achieved via crossing three main corpuses: first, the fundamental human needs (FHNs) coined by Max-Neef; literature on social sustainability associated with social capital; and finally, the different potentials of water urban context for achieving community social capital. Based on this conceptual framework, an in-situ approach along Al-Maryoutia Canal, Cairo, Egypt as a representative case study will be adopted to raise awareness and to understand the possible prospective potentials that these blue-green transects possess for achieving social capital in the Cairene urban context.

**Keywords:** Social sustainability (SS), social capital, connectivity, segregation, watercourses

## Introduction

*Isolationism* is a term used in a foreign policy; however, it can be introduced in the field of urban design as a strategy leading to spatial and social segregation. This isolation becomes a phenomenon that defines the contemporary urban fabric of many cities. This phenomenon can be seen, on the one hand, in the massive implementation of gated communities in addition to other forms of privatization of public spaces in malls, business parks, etc. On the other hand, it appears in the forms of imposed siege surrounding informal settlements. As a result, the community loses the crucial networks of relationships that enable it to function effectively, draining therefore its *social capital*.

As a mean to struggle against this phenomenon, we are interested in a particular urban topology, spaces along watercourses. Linearity, that characterizes these spaces, forms a potential of urban experience continuity. These linear configurations define a strategic urban scale capable of unifying current urban fragmentation and densification. They constitute a veritable occasion to rethink the city as a whole organism via providing a linkage “sewing” together the surrounding segregated neighbourhoods. In addition, watercourses define an ecological corridor that helps ameliorating the relationship between people and environment.

In this context, in Cairo, we focus on the network of the irrigation and drainage water canals of the former agriculture land located in the intersection between the rural and urban limits, delineating the capital from the north and the west. Despite the scarcity of water element in the gigantic metropolis, watercourses are joining nowadays the state of residual spaces considered as leftovers.

If accessibility and “connectivity” are a core concern in the sustainable future of cities, our aim is to rethink an intelligent transformation of the blue-green courses as an agent of “connectivity” on spatial, social and ecological levels. This urban configuration can participate in reinforcing a *social capital* through creating a common public space for everyday interactions and through ameliorating the quality of life and the habitability of local milieu. This shared space will help developing a common sense of ‘civic’ responsibility making therefore an engraved step towards *social capital* and in turn social sustainability (SS). In this optic, the main spine of this research will be embodying the concept of *social capital* through investigating the spatial role of blue-green transects and the different potentials they may afford for aggregating a more cohesive society.

### **Study methodology**

The research methodology seeks to establish a conceptual framework constituting the main potentials of linear spaces along watercourses as *satisfiers*, seen in terms of achieving *social capital*. This framework will be based on intersecting three main theoretical corpuses: fundamental human needs (FHNs), *social capital* and blue-green transects. This grid will then be applied and tested in an empirical study, a one kilometre along Al-Maryouttia canal as a representative case study. Based on *in-situ* approach and field observation, the objective is to identify the *spatial configurations* and *usage patterns* that may reinforce constituting a *social capital*. Crossing theoretical and empirical approaches result in raising awareness and understanding of the different prospective potentials that these blue-green possess for achieving *social capital* in the Cairene urban context.

### **Traversing fundamental human needs (FHNs), social capital, blue-green transects**

This section aims at sewing fundamental human needs, *social capital*, and blue-green transects in order to achieve a conceptual framework that could be a base for recreating water courses for more cohesive societies. This section will be presented in terms of three parts. The first one will explain the “theoretical merge” among FHNs, *social capital* and blue-green transects; followed by exploring FHNs satisfiers in relation to urban water context; and finally, a conceptual framework that correlates the FHNs with blue-green transects potentials/satisfiers towards social capital will be proposed.

#### **Theoretical merge**

*Social capital* is a major measure of SS that could be defined as a “quality of societies that signifies nature-society relationships, mediated by work, as well as relationships within the society, satisfying an extended set of human needs” (Integrated Network for Social Sustainability [INSS], 217). The social system described in the definition of SS will not endure unless the needs of most of its members are satisfied now and then. Thus, *social capital* is correspondingly relevant to the concept of the community members’ needs. In this respect, the Max-Neef theory of FHNs in which he relates the development process to the improvement in people’s quality of life for attaining social sustainability will be pursued. Max-Neef distinguishes between needs and satisfiers. He clarifies that human needs are constant in all cultures and throughout time. However, the variation between cultures is because of the different *satisfiers* they employ to satisfy their needs (Max Neef & Ekins, 2006). Max-Neef coined nine principal needs: *subsistence, protection, affection, understanding, participation, leisure, creation, identity* and *freedom*. He explained that needs are interrelated, not hierarchal and cannot be substituted for one another. A satisfier

may satisfy more than one need at once, synergic, while one need may require more than one satisfier in order to be fulfilled (ibid).

The subsequent question will be which needs are really associated to *social capital*? In this context, crossing literature reveals that the needs of *protection*, *affection*, *participation*, *creation*, and *identity* are the most listed needs to achieve social capital (Al-Dahmashawi et al., 2014); in the second rank comes the need of subsistence (Winther, 2010). Other needs are mentioned as a subcategory that takes part of another need, for example, need of freedom is mentioned in relation to safety, and leisure is associated with cooperation and participation issues (The Australian Bureau of Statistics [ABS], 2002). If the need of understanding has not been mentioned directly in relation to *social capital*, however, it can be included since it is relevant to the aspects of better communication.

Concerning the capacity of linear configurations in creating *social capital*, the three relations of *bonding*, *bridging* and *linking* that define *social capital* should be explained. The difference depends on to the scale of the place-bound and the degree of *heterogeneity/homogeneity* of the social network. *Bonding* has the function to “bond” the actors of the same spatial and organizational unit with certain degree of homogeneity. It constitutes social group and secure the solidarity and cohesion of the unit. While, *bridging* tends to connect the group and its actors with the “rest of the society”; it gathers the different groups that share common interests but with higher degree of heterogeneity. If *bonding* and *bridging* establish horizontal relationships; *linking* on the contrary, defines *social capital* as vertical relationships between actors with different possessions of power (Westlund et al., 2013).

Blue-green transects could be a unique urban context for boosting social networks. They could bond, bridge and link the community via their spatial continuity that engenders a common territory between different neighbourhoods creating therefore a platform for multi-functionality. In this context, the renovation of such blue-green transects via enhancing their functions towards achieving *social capital* as a type of landscape could be considered as socio-natural processes. Concerning the term multi-functionality, any public designed landscape can have multiple environmental, social and economic functions in addition to configuration, and maintenance and operation functions. Configuration functions are fundamental for the creation of a space, while maintenance and operation are important for sustaining it (Lovell & Johnston, 2009; Selman, 2008).

### ***Exploring blue-green transects potentials towards social capital***

This part explores the blue-green potentials/satisfiers of FHNs towards *social capital*. Investigating potentials for satisfying needs will adopt the same order provided by Max-Neef considering the subcategories mentioned above.

#### ***Subsistence***

The basic meaning of subsistence is the essential necessities for human existence and survival. Attributes related to subsistence consist of physical, mental, and emotional health. Concerning blue-green transects, human health is seen mentally in experiencing nature that helps in recovering from mental fatigue of work or studies. Nature, when incorporated into urban and building design, provides calming and inspiring environments and encourages learning and inquisitiveness (Urban Forestry/Urban Greening Research [UFUGR], 2016). Physically, blue-green transects could support physical activities and areas for play. Emotionally, such spaces support social settings important for social communication, and



sense of belonging. In addition, such spaces can support work, financial and food resources (American Public Health Association [APHA], 2013).

#### *Protection and freedom*

The term protection could be substituted by the term safety used by Maslow, which is more consistent with what we approach as an abstract need. In this sense, Blue-green transects could support safety on two levels, physically (environmental or social hazards) and psychologically. Providing accessible public spaces in which walking and cycling routes, approaches to buildings and public transport facilities maximize feelings of safety and reduce anti-social behaviour, encourage greater use and thereby physical activities (Whitzman 2008, p. 234; Foster 2008). Therefore, the quality of space design via balancing prospect and refuge and spaciousness and crowding; considering building design, privacy and ownership boundaries, and finally keeping maintenance issues are all aspects that affect safety and in turn freedom to socialize (Healthy Spaces and Places [HSP], 2009). Freedom ensures accessibility, legibility, mobility, participation and flexibility issues.

#### *Affection*

Affection could be understood in terms of the emotional tonality that accompanies the lived experience and the relationship that people establish with nature. In the context of blue-green transects, affection is a kind of positive connection and a topophilic feeling that results from relevant and delightful spatial qualities associated with targeted functions. Positive connection could be understood in terms of: *character* and *legibility*; and *orientation* and *imageability* of space. Namely, what are the services (functions) and how they are presented in order to facilitate social interactions allowing people to be involved in shared experiences? The more fitting *legibility* and impressive *imageability* are realized, the more positive connection revives with places (Hassan, 2012). *Legibility* insists on the readability of spaces, while *imageability* enhances powerfully structured mental images.

#### *Understanding*

Understanding spaces in terms of their physical features is a critical step. It is the mechanism that facilitates and boosts the meeting of the other needs. Understanding can help us to create meaning to enhance our experiences. Understanding need is associated with two aspects, the spatial qualities that support communication and the human need for knowledge. Space design should consider *coherence*, *legibility* and *exploration experience*. (Hassan, 2012). On the other hand, the concept of Knowledge in relation to *social capital* could be seen in providing learning opportunities for all while sharing the same experience, through boosting biodiversity.

#### *Participation and leisure*

Community participation is considered a key element in achieving *social capital* and in turn, sustainable development while ensuring the principle of “rights and responsibilities” (Mahjabeen, Shrestha & Dee, 2009). Participation in our context can be participation *in design*, the participation of users in the actual design process, and participation *through design*, operation and usage (Granath, 2010). Participation *in design* could be approached via encouraging diversity in design teams; and ensuring that people have influence over decisions. On the other hand, participation *through design* could be achieved through supporting *accessibility*, comprehension and ownership of the facility; and integrating any public facility in the surrounding neighbourhoods ensuring the concept of *versatility* to support different forms of social interactions.

### *Creation*

Based on different studies, it was proved that creativity is relevant to *social capital* and its impact on economic performance. These studies emphasized the role of the social interactions among *heterogeneous* groups in the creative processes or at least initiating it (Koestler, 1964). In fact, the linearity of blue-green transects and their capacity to traverse varied urban districts develops a common interest among different local milieu where the variety of experiences, knowledge and education among inhabitants can meet. In brief, *in design* such blue-green transects, creativity could be achieved via creating more rich and free press. Encouraging innovations that emerge from the local context may provide new solutions for specific constraints, and allowing future users to create via engaging in design practice. On the other hand, creativity *through design* could be kindled through biodiversity that can stimulate creative behaviour; and through the diverse social interaction (Hassan & Al-Dahmashawi, 2016).

### *Identity*

Identity is associated with the attributes of a place that tell us about its physical and social context. Identity develops through socio-cultural meanings and symbols associated with specific group of people in certain place. However, these meanings are renegotiated continually and therefore their contribution to identity is never the same (Hauge, 2007). Like affection, identity is expressed in terms of the spatial qualities associated with targeted functions and surrounding uses (Lacilla & Ordeig, 2016). The continuous use of spaces develops attachment and builds certain image, and this happens when these functions satisfy peoples' functional and behavioural needs. Attachment here is deeper than that caused by affection, it is associated with history, memories, culture and symbols, creating sense of belonging, ownership, and place resulting from being free to use them regularly (Dougherty, 2006; Ujang, 2012).

### ***The conceptual framework***

Based on the first two parts of this section, a conceptual framework is proposed to illustrate the relation between the FHNs with different functions of blue-green transects towards achieving social capital Table 1.

### **Findings and discussion of the in-situ study crossing the conceptual framework**

Based on an in-situ study, a one kilometre situated in the intersection between the city and its rural fringes is selected as a representative case study along Al-Maryouttia Canal. The objective of this lived experience is to examine the different potentials that this space possesses in favour of achieving *social capital*. Grounded on the aforementioned conceptual framework, directing a floating observation pointing out the change in experience was achieved. Documenting observation data depended on taking notes and visual methods helped capturing different *usage patterns* and particular *spatial configurations* that may constitute a potential for future satisfiers for FHNs in terms of *social capital*. The lived experience at the selected area revealed specific scenes that were analysed according to the conceptual framework. Scenes are indicated by letters and inserted in Table 1 corresponding to the potentials they denote. Captured key scenes presented as excerpts extracted from the whole story of the lived experience as follows Table 2:

Table 1. Conceptual framework crossing the FHNs with blue-green transects potentials towards *social capital*

FHNs	Blue-green transects functions/satisfiers towards <i>social capital</i>				
	Configuration functions	Environmental functions	Social functions	Economic functions	Maintenance and operation functions
<b>Subsistence</b>	<ul style="list-style-type: none"> <li>Experiencing nature (<i>mental health</i>) [H]</li> <li>Creating spaces for physical activities and children play (<i>physical health</i>)</li> </ul>		<ul style="list-style-type: none"> <li>Supporting social setting for social life and shared events and public celebrations (<i>emotional health</i>)</li> </ul>	<ul style="list-style-type: none"> <li>Providing work, and food (<i>mental, physical, emotional health</i>) [D, H]</li> </ul>	
<b>Safety and freedom</b>	<ul style="list-style-type: none"> <li>Balancing prospect and refuge possibilities (<i>physical and psychological safety</i>) [F]</li> <li>Emphasizing legible landscape morphology (<i>freedom-legibility</i>)</li> <li>Creating approaches, entrances and exits (<i>freedom-accessibility</i>) [F]</li> <li>Building well-designed paths network (<i>freedom-mobility</i>)</li> <li>Varying experience opportunity (<i>freedom-versatility and flexibility</i>) [F]</li> </ul>	<ul style="list-style-type: none"> <li>Providing shelters from natural hazards (<i>physical safety</i>) [F]</li> </ul>	<ul style="list-style-type: none"> <li>Boosting walking and cycling via integrating their routes (<i>physical and psychological safety</i>) [F]</li> <li>Differentiating privacy settings (<i>physical and psychological safety</i>)</li> <li>Emphasizing sense of ownership and ownership boundaries (<i>physical and psychological safety</i>)</li> <li>Supporting social setting (<i>freedom-participation</i>) [D]</li> </ul>		<ul style="list-style-type: none"> <li>Keeping maintenance infers safety and encourages social interaction (<i>psychological safety</i>) [C]</li> </ul>
<b>Affection</b>	<ul style="list-style-type: none"> <li>Enhancing personality of function [E,G]</li> <li>Emphasizing orientation and <i>imageability</i> [A,H]</li> </ul>		<ul style="list-style-type: none"> <li>Supporting social setting for social life and shared events and Public [A,D]</li> </ul>		
<b>Understanding</b>	<ul style="list-style-type: none"> <li>Considering design concept, form, materials, and morphology (<i>coherence and exploration</i>)</li> <li>Supporting well-defined spaces, thresholds, routes network and landmarks (<i>legibility</i>) [B, G, H]</li> </ul>	<ul style="list-style-type: none"> <li>Supporting biodiversity creates opportunity for shared experience (<i>knowledge</i>) [H]</li> </ul>	<ul style="list-style-type: none"> <li>Provide places for cultural, educational and awareness opportunities for all sharing the same experience (<i>knowledge</i>) [B, H]</li> </ul>		
<b>Participation and leisure</b>	<ul style="list-style-type: none"> <li>Utilizing the linearity and continuity of blue-green transects in encouraging diversity in design teams (<i>participation in design</i>) [C]</li> <li>Integrating blue-green transects in the surrounding territories (<i>accessibility and versatility for participation</i>) [G]</li> </ul>		<ul style="list-style-type: none"> <li>Emphasizing sense of ownership via cultural symbols and memories (<i>participation through design</i>) [C]</li> <li>Supporting social setting for social life and shared events and Public Celebrations (<i>participation through design and leisure</i>) [A, F, H]</li> </ul>		
<b>Creation</b>	<ul style="list-style-type: none"> <li>Utilizing the linearity and continuity of blue-green transects in encouraging diversity that stimulates creativity [A]</li> <li>Enhancing richness in design through the elements of landscape design manipulating water, vegetation, built elements and landform [D, H]</li> </ul>	<ul style="list-style-type: none"> <li>Supporting biodiversity could evokes ideas [D, H]</li> </ul>	<ul style="list-style-type: none"> <li>Designing considering local cultures for innovative materials and techniques [E]</li> </ul>		
<b>Identity</b>	<ul style="list-style-type: none"> <li>Emphasizing surrounding uses (<i>sense of belonging and sense of place</i>) [D, H]</li> <li>Using symbolic cues associated with culture, history and memories (<i>sense of belonging and sense of place</i>) [B, E, H]</li> </ul>	<ul style="list-style-type: none"> <li>Respecting local nature and environment [D, H]</li> </ul>	<ul style="list-style-type: none"> <li>Merging supported functions and services with culture to enhance social interaction (<i>sense of belonging and sense of place</i>) [E, H]</li> </ul>	<ul style="list-style-type: none"> <li>Respecting local heritage supports work and food [H]</li> </ul>	

Table 2. Key scenes excerpted from the lived experience

Key scenes	Snapshots
<p><b>Blue-green and affective tonality [A]</b></p> <p>The space along Al-Maryouttia is considered as an urban pocket where people meet nature. The presence of water, greenery and biodiversity provide a portion of land where people can escape from the stifling urban conditions of the city. Despite the noisy soundscape as one of the main entrances to the capital, certain practices seeking tranquillity towards rural areas were captured. This was seen in limited family picnics; people seek refuge while enjoying nature. Experiencing nature along the canal is often accompanied by an emotional tonality alternating from relaxing, relief, on the one hand, and regret and sorrow on the other hand.</p> <p><i>Scene interpretation:</i> Blue-green and affective tonality could be a potential for creating positive <i>versatility</i> that could support <i>legibility</i>, <i>imageability</i>, biodiversity and different social settings, which finally affect affection, participation and leisure, and creation via configuration, environmental and social functions of the context.</p>	 <p>Water, greenery and biodiversity</p>  <p>Limited family picnics</p>
<p><b>Gathering faraway and near horizons [B]</b></p> <p>The linearity of the canal reaches faraway horizons, overlapping with the nearby one. Gathering faraway and near horizons create a panoramic prospect that merges different territories characteristics, urban, rural, and historic.</p> <p><i>Scene interpretation:</i> The visual continuity gives a sensation of freedom and liberty and allows a room for creativity, imagination and prospect; a perspective that the city rarely affords due to its hyper density. These features affect legibility, imageability, versatility, cultural experiences, sense of belonging and sense of place. These potentials could be satisfiers for freedom, understanding, and identity through landscape configuration and social functions.</p>	  <p>Faraway and near horizons</p>
<p><b>Interventions [C]</b></p> <p>An NGO called Ressalat Nour ala Nour whose main office is located at the canal towards its rural side, pursued aesthetic restorations to ameliorate and preserve the greenery along the canal. In this esthetical vision, the NGO expressed a certain responsibility for beautifying the entrance of Al-Maryouttia road as a main touristic route to the great pyramids. Other vulnerable actions like fixing a bench situated along the canal are also captured.</p> <p><i>Scene interpretation:</i> These fragile gestures initiated by the inhabitants mark the potentiality of this space towards a participatory approach. The varied investments along the space highlight the crossing interest between different city actors. The linearity and continuity of the place that traverse different territories, in addition to the shared experiences in the daily life among certain social groups affect the sense of ownership and participation and leisure via its configuration, social and maintenance functions.</p>	 <p>An NGO aesthetic restoration</p>  <p>A gesture seeks to maintain this space as a refuge and as an encountering space</p>



### **Marginal social security resources [D]**

Despite their informal character and the apparent deliberate status, we can underline specific activities that may constitute the main income for certain families. Planting parcels along the canal can enter in the case of urban agriculture, a practice that joins a vision towards urban and ecological sustainability. It integrates parts of the rural presence in the city, preserving villager's practices. Other forms of activities such as mobile cafés, ambulant vendor and informal markets are settled along the canal providing some services to the passers-by.

*Scene interpretation:* Amazingly this scene of the marginal social security resources is extremely synergic. It shows that this context holding up for work, financial resources and food, which in turn affect the sense of ownership supporting different social interactions. Biodiversity and such activities creates context full of diverse experiences. In addition, such practices maintain socio-cultural values of the place. This scene has the potentials to support subsistence, safety, affection, creation and identity through configuration, environmental, social, and economic functions.



Limited urban agriculture



Informal markets

### **Micro-society [E]**

Photography proved the existence of a micro-society, in particular among villagers. This is manifesting in specific usage patterns and appearance such as using animals' carts for mobility, their appearance in the folk costume of the Egyptian villagers. These scenes reinforce the presence of the rural life within this urban context. Other minor gestures show inter-linking ties between inhabitants of this micro-society such as exchanging greetings and encounters in public spaces on daily-bases.

*Scene interpretation:* This scene plays a significant role as a potential for enhancing place character considering local cultures and symbolic cues associated with the daily life usage pattern. These possibilities could be satisfiers for affection, creation and identity via configuration and social functions.



Greetings in public



Animal cart

### **Bridges [F]**

Certain urban facilities such as pedestrian bridges provide a point of encounter and gathering places. People prefer these places due to the natural view and the visual openness they offer. In the northern part of the canal, spaces underneath the flyover provide a sort of refuge. Perceived as a roof protecting space users from the sunrays, the space accommodates certain activities such as a cultural centre.

*Scene interpretation:* This scene has the possibilities for supporting prospect and refuge, approaches, accessibilities and shelters that all enhances different social activities and interactions. Therefore, this scene provides satisfiers for safety, freedom, participation and leisure via configuration, environmental and social functions.



Pedestrian bridge



Culture center underneath the flyover



### Threshold [G]

Despite the drastic thresholds appear along Al-Maryoutia Canal, we still feel its linearity. This linearity affects space coherence, while these thresholds create repulsive legibility and imageability. These thresholds can be identified at the intersection between the city and the rural context constituting a clean-cut, which is reinforced by the presence of the fly-over of the Ring road. At this point, the spatial configuration suffers from a radical change; the greenery disappears abruptly, the heavy traffic starts to dominate the soundscape, the presence of high-rise buildings delimiting both sides. Other minor thresholds part the sequences creating sudden micro-ambiances; the difference between natural plantation along the canal and designed landscapes by the NGO.

Scene interpretation: These drastic thresholds could be a potential for recreating the place. These margins could be developed to create harmonious *versatility* via overlapping transformations figured through these thresholds, where mediating different experiences occurs. Boosting for positive thresholds affects safety and freedom, affection, understanding, participation and leisure through configuration functions.



Drastic thresholds

### Water as memory and heritage [H]

In fact, the memory of water in the Egyptian context crossing several times going back to the Pharaonic times reveals the sacredness of water as a main source of life. Certain natural features such as an old tree with dense foliage, cattle egret known in the Egyptian culture as the “friend of peasant” were captured. Despite the rarity of their presence, these minor features activate the memory and unfold an anterior temporality of this part of the city as former agriculture land. The current situation of the canal indicates a memorial rupture between the past and the present.

Scene interpretation: Watercourses are precious natural resources that configure particular landscapes both by the physical and aesthetic qualities. Water can be considered in itself an immaterial heritage due to the particular experience it offers and as a bearer of the sedimented memory. If the current situation of the canal indicates a memorial rupture between the past and the present, the relation to water should be revived through its different ambient characteristics. This scene which appears in the scarce agricultural lands attached to the canal could be a possibility for boosting more related memorial activities such as fishing, and boating. These marginal social practices could be extremely synergic potentials for satisfying subsistence, affection, understanding, participation and leisure, creation, and identity through the most of landscape functions.



Cattle egret



Old boat



old tree with dense foliage

According to the findings of the in-situ approach and the interpretations of the key scenes excerpted from the lived experience, different relations among these scenes as potentials for satisfying the FHNs towards *social capital* via different landscape functions were unfolded in Figure 1, revealing specific values that could be discussed as follows:

- Water as memory and heritage is the most synergic scene that has potentials for satisfying almost all the FHNs. Gathering faraway and near horizons, and marginal social security resources come at the second level as synergic scenes followed by blue-green and affection tonality, micro-society and thresholds. While interventions and bridges come last.

- Marginal social security resources and water as memory and heritage are the most collective scenes based on the functions they support. These scenes reveal possibilities through all functions, except maintenance and operation; while threshold provide only configuration functions.
- Configuration and social functions are the most listed functions of the emerged scenes, while maintenance and operation comes last.

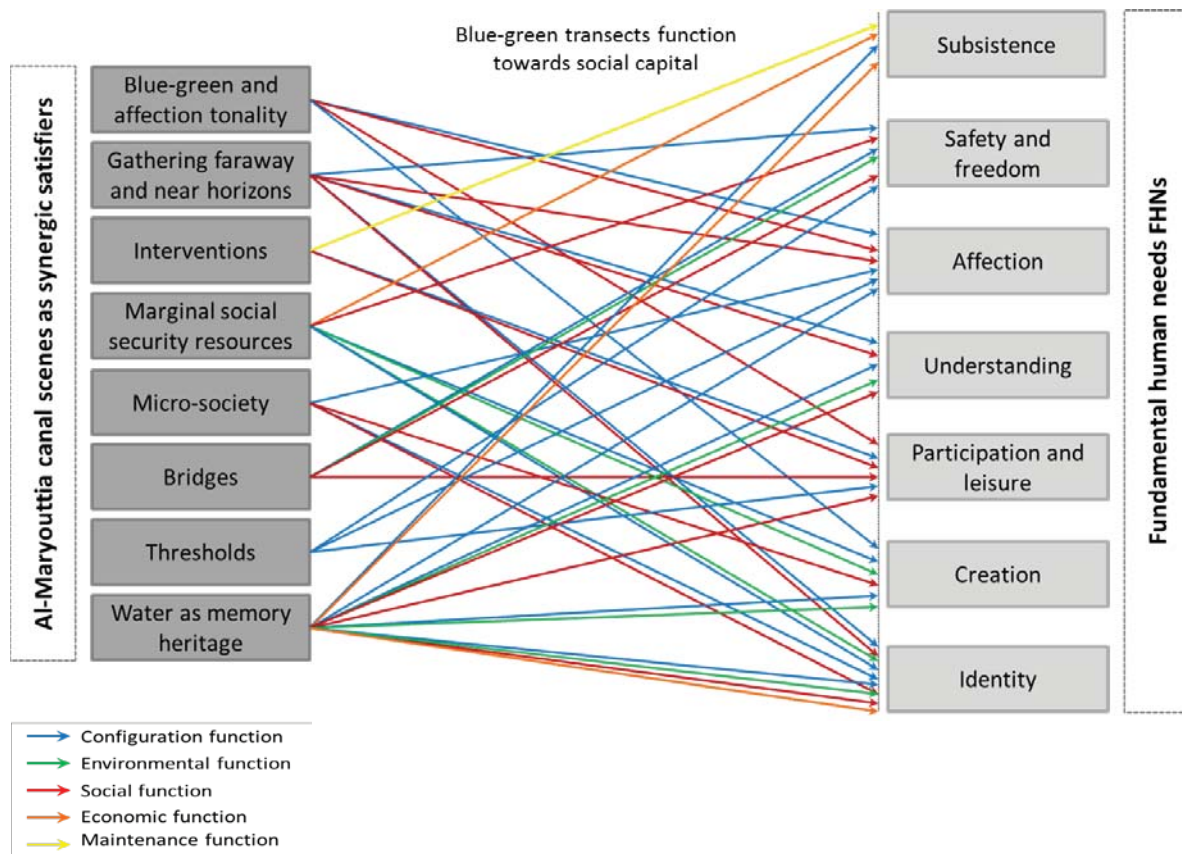


Figure 1 Al-Maryouttia canal potentialities as blue-green transects functions/satisfiers towards *social capital*

## Conclusion

The socio-spatial isolationism phenomenon is usually multi-dimensional and interrelated that require correlated solutions on different levels and dimensions. If Isolationism results in society segregation, it opposes to the concept of “connectivity” as a major clue for achieving social capital and in turn SS. This concept should be significantly reinforced through social and physical processes. Thus, the aim was boosting for *social capital* via supporting “connectivity” through the configuration of blue-green transects as a unique urban topology. Crossing literature review on *social capital*, FHNs and watercourses have showed that large-scale linear configurations as a type of landscape can provide a spatial unity with continuous shared experience through its different functions in order to satisfy surrounded societies’ needs. The linearity and continuity of such spaces can activate the three types of linkage – *bonding, bridging and linking* – since it constitutes an “interaction arena”.

In this respect, observations along Al-Maryouttia canal, has spotted the presence of a small community of villagers *bonded* together by the agricultural activity. Despite its informal and fragile character, the agriculture activity retains social interactions among them and reinforces their presence in public space. This lived reality cannot be ignored when we are interested in aggregating a *social capital*. In same optic, it is crucial to imagine

the prospective capacity of this space stepping forward to *bridging* this marginal community of villagers with other social categories. This deliberate transformation will enhance accessibility and will boost the co-presence of different social classes and invite them to share this particular experience that this space may afford. In addition, the small interventions whether informal (by individual inhabitants) or formal (the intervention of the NGO in certain parts of the space in agreement with the city council), reflect an undeniable shared interest among different city actors. This underlines the capacity of these linear configurations in *linking* space users to decision-makers and carries the seeds towards a participatory approach.

On the other hand, these types of linkage could be materialized taking into account the potentials of the captured scenes. In this sense, the in-situ approach reveals that specific scenes should be tackled seriously since they have potentials to be synergic satisfiers for FHNs towards achieving *social capital*. Water as memory heritage shows large capacity for “connectivity” via being synergic satisfier meeting almost all of FHNs and through different configuration, environmental, social and economic functions as a type of urban landscaping. Furthermore, the scenes of gathering faraway and near horizons, and marginal social security resources reflects the importance of utilizing the feature of continuity and the different marginal practices and uses essential for subsistence for certain social groups.

Finally, it should be underlined that the massive transformation and the radical disappearance of blue-green courses creates clear-cut threshold that in turn announces a threat and leaves a strong message to be taken into consideration in the relationship among the different society’s social sectors. According, water courses, as a natural element, and its linearity and continuity, beside its capacity for social resources should be at the top consideration for any urban development.

## References

- Al-Dahmashawi, D.; Hassan, D.; Sabry, H.; Kamel, S. (2014). Incorporating Social Sustainability Themes in the Built Environment. *The Journal of American Science*, Vol: 10, Issue: 5, p. 141-151,
- American Public Health Association. (2013). *Improving Health and Wellness through Access to Nature*. Url: <https://www.apha.org/policies-and-advocacy/public-health-policy-statements/policy-database/2014/07/08/09/18/improving-health-and-wellness-through-access-to-nature>
- Claridge, T. (2004). Evolution of Social Capital. *Social Capital Research*. Url: <https://www.socialcapitalresearch.com/about-this-site.html>
- Costanza, R.; Fisher, B.; Ali, S.; Beer, C.; Bond, L.; Boumans, R.; ... Farley, J. (2007). Quality of life: An approach Integrating Opportunities, Human Needs, and Subjective Well-being. *Ecological Economics*. 61(2), 267–276.
- Department of Health and Ageing. (2009). *Healthy Spaces and Places. Design Principle – Safety and Surveillance*. Department of Health and Ageing. Url: <https://www.healthyplaces.org.au/userfiles/file/Safety%20and%20Surveillance%20June09.pdf>
- Dougherty, D. L. (2006). *Embodying the city: Identity and use in urban public space*. Master of Landscape Architecture. Alexandria, Virginia
- Foster, S. and Giles-Corti, B. (2008). *The built environment, neighborhood crime and constrained physical activity: An exploration of inconsistent findings*. Preventive Medicine, doi:10.1016/j.ypmed.2008.03.017
- Granath, Å. (2010). Participation of Users in Architectural Design in: Karwowski, W. ed., *International Encyclopedia of Ergonomics and Human Factors*. (Boca Raton, FL, CRC Press). pp. 2221-2225.
- Hassan, D.; Al Dahmashawi, D. (2016). Design for Social Sustainability: Incorporating Social Sustainability Themes in Planning and Designing Primary Schools. *Engineering Research Journal*. Faculty of Engineering, Shoubra, April.
- Hauge, Å. (2007). Identity and Place: A Critical Comparison of Three Identity Theories. *Architectural Science Review*. DOI: 10.3763/asre.2007.5007

- Integrated Network for Social Sustainability [INSS]. (2017). Defining Social Sustainability. National Science Foundation, Url: <https://clas-pages.uncc.edu/inss/what-is-social-sustainability/>
- Koestler, A. (1964). *The Act of Creation*. London: Hutchinson & Co.
- Lacilla, E.; Ordeig, J. M. (2016). Waterfront Public Realm Design: Towards a Sustainable Identity Urban Projects in Vancouver and Portland. *Journal of Sustainable Development*; Vol. 9, No. 2; 2016 ISSN 1913-9063 E-ISSN 1913-9071
- Lovell, S. T., & Johnston, D. M. (2008). Creating Multifunctional Landscapes: How Can the Field of Ecology Inform the Design of the Landscape? *Frontiers in Ecology and the Environment*, 7(4), 212–220
- Mahjabeen, Z.; Shrestha, K.; Dee, J. A. (2009). Rethinking community participation in urban planning: The role of disadvantaged groups in Sydney Metropolitan Strategy. *Australasian Journal of Regional Studies*. Vol. 15. No. 1. Url: <http://anzrsai.org/assets/Uploads/PublicationChapter/289-Mahjabeen.pdf>
- Max-Neef, M. (1991). *Human Scale Development: Conceptions, Applications and Further Development*. Newyork and London: New York: The Apex Press.
- Max Neef, M., & Ekins, P. (2006). *Real Life Economics*. Routledge.
- Hassan, D. (2012). *People and Open Spaces: Psychological Contentment and Landscape narratives*. Lmbert Academic Publisher.
- Oakes, C. G. (2014). *The Bollard: Non-Crash and Non-Attack-Resistant Models*. Retrieved March 5, 2016, Url: <https://www.wbdg.org/resources/bollard.php>
- Oxford Dictionaries. (n.d.). Protection. Oxford Dictionaries. Retrieved from <http://www.oxford>
- Selman, P. (2008). What do We Mean by Sustainable Landscape. *Sustainability: Science, Practice, & Policy*, 4(2), 23–28.
- The Australian Bureau of Statistics. (2002). *Social Capital and Wellbeing*. Commonwealth of Australia. Url: <https://www.oecd.org/innovation/research/2380806.pdf>
- The World Bank. (2011). *Social Capital*, Url: <http://web.worldbank.org/WBSITE/EXTERNAL/TOPICS/EXTSOCIALDEVELOPMENT/EXTTSOCIALCAPITAL/0,contentMDK:20185164~menuPK:418217~pagePK:148956~piPK:216618~theSitePK:401015,00.html>
- Ujang, N. (2012). Place Attachment and Continuity of Urban Place Identity. *Procedia - Social and Behavioral Sciences* 49 (2012) 156 – 167, doi: 10.1016/j.sbspro.2012.07.014
- Urban Forestry/Urban Greening Research. (2016). *Mental Health and Function*. University of Washington, College of the Environment. Url: [https://depts.washington.edu/hhwb/Thm\\_Mental.html](https://depts.washington.edu/hhwb/Thm_Mental.html).
- Westlund, H. ; Andersson M. ; Karlsson, C. (2013). *Creativity as an integral element of social capital and its role for economic performance*. The Royal Institute of technology: Centre of Excellence for Science and Innovation Studies.(CESIS). Paper No. 330.
- Whitzman, C., (2008). *The Handbook of Community Safety, Gender and Violence Prevention Practical Planning Tools*. Earthscan London, Sterling, Virginia, USA
- Wilson, K.; Hannington, S.; Mukiibi, S. (2015). The Role of Community Participation in Planning Processes of Emerging Urban Centres. A study of Paidha Town in Northern Uganda. *International Refereed Journal of Engineering and Science (IRJES)*, Volume 4, Issue (June), PP.61-71. Url: <http://www.irjes.com/Papers/vol4-issue6/H466171.pdf>
- Winther, G. (ed). (2010). *The Political Economy of Northern Regional Development*. Copenhagen: Nordic Council of Ministers.



# Exploiting Sustainable Managing Resources for Heritage Tourism in El Alamein, Egypt

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## Abstract

Today, heritage-based tourism has emerged as a leading growth sector in global tourism markets. Natural and cultural heritage can fully provide the development of tourism by exploiting intellectual and material resources. It is important to understand these resources as including not only cultural institutions, museums and historic monuments, but also all ancillary resources related with tourism services, such as historical and cultural monuments, historical and cultural centers, sites of important cultural events, natural heritage and other places of worship, cemeteries, etc. Hereby, heritage tourism is considered to encompass elements of living culture, history, and natural history of place that count as community's value for the future. These elements are very specific to a community or region. To maximize the revenue potential offered by the heritage tourism industry, it is necessary to give more technical attention to managerial guides and sustainable development principles on their components. It could be reached by better fit of tourism development or planning along with a better understanding of natural and cultural tourism.

Thus, the aim of this study is not on primary cultural heritage objects, but on resources which have a better implementation in managing the sustainability in tourism destinations in El Alamein as a final objective. To tackle the objective of this paper, firstly, definitions of cultural and natural heritage were stated. Secondly, the linkage between heritage and tourism were emphasized. Moreover, the case study of El Alamein, as a tourism destination in Egypt, was analyzed by implementing sustainable managing resources for tangible and intangible heritage elements. Results of this paper took the form of managerial guides and sustainable development principles of the heritage tourism industry resources.

**Keywords:** Heritage Tourism, Sustainable Development, Managing Resources, El Alamein.

## Introduction

According to the World Tourism Organization, heritage-based tourism is growing globally at a rate of 15 % per year, and at the same time 37% of all trips nowadays contain a cultural component (WTO, 2009). Saarinen and Rogerson (2015) posit that cultural tourism is perceived as one of the major development opportunities for Africa, while Loulanski and Loulanski (2011) explored the relationship between tourism and cultural heritage. Their results revealed a representative set of synthesis factors aimed at achieving sustainability. Natural and cultural heritage can fully provide the development of tourism by exploiting intellectual and material resources.

Thus, heritage tourism can be a vehicle for conservation and preservation of heritage; it can create interest and appreciation that may become a catalyst in its protection. Moreover, the interest of outsiders in heritage may also galvanize local residents to act to protect a place once they realize that the heritage has cultural or historical significance, or at least has proven it has economic value. Hereby, heritage tourism is considered to encompass elements of living culture, history, and natural history of place that count as community's value for the future. These elements are very specific to a community or region. To maximize the revenue potential offered by the heritage tourism industry, it is necessary to give more technical attention to managerial guides and sustainable development principles on their components. It could be reached by better fit of



tourism development or planning along with a better understanding of natural and cultural tourism.

The structure of this paper consists of five sections relating to the managerial guides and sustainable development principles of the heritage tourism industry resources. The first section introduces definitions of cultural and natural heritage; the second section briefly follows the main dimensions of the sustainability in heritage tourism industry, reporting that tourism development can help reduce unsustainable exploitation of natural resources and promote heritage conservation efforts. The third section contains a summary of cultural and natural heritage tourism destination in El Alamein, Egypt; while the fourth section provides the general objectives of sustainable managing resources to improve resource utilization for the development of heritage areas. Finally, managerial guides and sustainable development principles of the heritage tourism industry resources are being intended by analyzing resources which have a better implementation in managing the sustainability in tourism destinations.

### **Definitions of Cultural and Natural Heritage**

According to the UNESCO Convention on the Protection of the World Cultural and Natural Heritage, adopted by the General Conference of the United Nations Educational, Scientific and Cultural Organization in 1972, heritage sites can be divided into cultural heritage and natural heritage sites (UNESCO, 1972). Cultural heritage may be tangible or intangible (Qajja, 2005). There are also mixed heritage sites that include natural and cultural sites. Heritage sites can be declared as follows:

#### ***Tangible Cultural Heritage***

In accordance with the Convention for the Protection of the World Cultural and Natural Heritage, tangible cultural heritage sites (UNESCO, 1972) consist of:

- Monuments: architectural works, monumental sculpture and painting, elements or structures of an archaeological nature, inscriptions, cave dwellings and combinations of features, which are of outstanding universal value from the point of view of history, art or science;
- Complexes: groups of separate or connected buildings that have exceptional universal value from the point of view of history, art or science because of their architecture, consistency, or integration into a landscape;
- Sites: man-made works or a combination of natural and man-made works, and areas including archaeological sites of outstanding universal value from the historical, aesthetic, ethnological or anthropological point of view.

#### ***Intangible Cultural Heritage***

According to Muhammad Qajja (Qajja, 2005), intangible or spiritual cultural heritage is a system of values and traditions like oral tradition and other forms of human communication where knowledge, art, ideas and cultural materials are received, based on spatial or temporal dimensions.

#### ***Natural Heritage***

According to the UNESCO Convention on the Protection of the World Cultural and Natural Heritage nature heritage can be defined as (UNESCO, 1972):

- Natural sites that consist of physical or biological formations are of exceptional universal value from an aesthetic or scientific point of view.
- Geological or physiological formations and finely defined areas comprising animal species, habitats and endangered plants.

### **Sustainability in Heritage Tourism Destination**

Two decades ago, the term of sustainable tourism started to be used (May, 1991, Nash and Butler, 1990). One of the first definitions that were assigned to sustainable tourism by the United Nation World Tourism Organization is (UNWTO, 1996): "tourism which leads to management of all areas, in such a way, that the economic, social and environmental needs are being fulfilled with the cultural integration, ecological processes, biodiversity and supporting the development of societies". Additionally, (UNWTO, 1996) sustainable tourism was explained as a process that "takes into account the needs of present tourists and traveller needs of the future generations as well". Figure 1 describes the main dimensions of the sustainability in tourism industry:

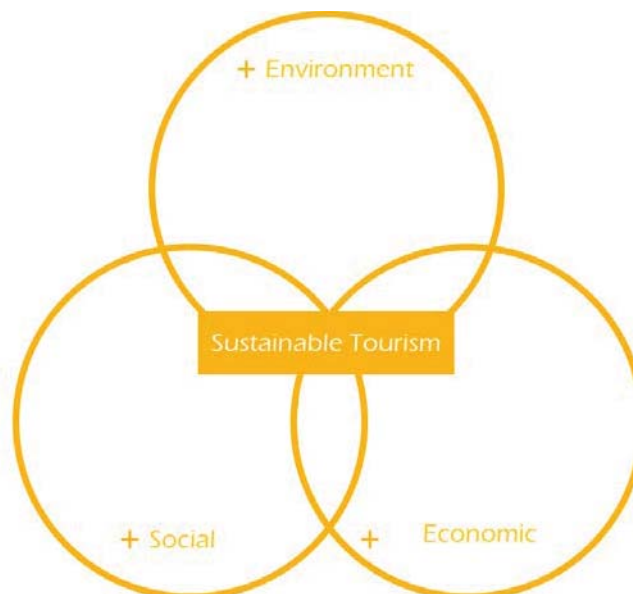


Figure 1. The Main Dimensions of the Sustainability in Tourism Industry  
Source: Sustainable Tourism Online

Heritage tourism was to be considered different from tourism as a general concept (Leask and Goulding, 1996). Its main objective is to preserve the historical properties and maintain them in good status focusing on comprising conservation aims with financial and public access constraints (Croft, 1994).

Heritage tourism is highlighted as one of the fastest-growing sectors of the global tourism economy as estimated, 40% of international leisure tourism involves a cultural component (Novelli 2015). Well organized heritage tourism creates opportunities for creating a balance between tradition and innovation, supporting the protection,

conservation and restoration of historical and cultural monuments, and finding a compromise between conservation and visitor needs (Dolgorsüren, 2004).

Researchers asserted that if heritage tourism is sustainably managed it can contribute to the development of the local community and to the management and conservation of heritage sites for future generations (e.g. Hughes and Carlsen, 2010; Lindberg et al., 1999; UNEP, 2005). This is mainly because it can help increase financial support for conservation from governmental institutions as well as national and international tourism parties and donor agencies, raising awareness among visitors and local communities (UNEP, 2005) and encouraging indigenous people to value their local culture (Nasser, 2003). Tourism development can then help reduce unsustainable exploitation of natural resources and promote heritage conservation efforts.

## **Cultural and Natural Heritage Tourism Destination in El Alamein, Egypt**

### ***Natural Heritage in El Alamein***

El Alamein contains different types of environments, biological communities, land use patterns and desert settlements. In order to protect the natural resources and biodiversity in El Alamein and to maintain the ecological stability, Al-Omaid Nature Reserve has been declared, reflecting the beauty of nature and natural resources (EEAA, 2008).

### ***Al-Omaid Nature Reserve***

Al-Omaid Nature Reserve is located in the west of Al-Hammam city, 80 km from Alexandria Governorate, 30 km west and 3.25 km from the Mediterranean coast to the south. It was proclaimed in 1986 as an area of 705 km<sup>2</sup> and was declared by UNESCO in 1981 as part of the International Biosphere Reserves Network of the International Human and Biosphere Program (EEAA, 2008).



Figure 2. Al-Omaid Nature Reserve Location

Source: Google Maps

Environmental research has shown that Al-Omaid is one of Egypt's richest regions in its plant and animal biodiversity, which includes more than 864 species. It contains different types of environments, biological communities, land use patterns and desert settlements.

### ***Aims of Al-Omaid Nature Reserve***

- The conservation of plants and animals as natural resources within ecosystems because of their importance, especially medicinal, therapeutic and pastoral species, and their development to achieve their sustainability.
- Promote environmental awareness among local communities, school students, universities and research institutes and encourage them to conserve natural resources that benefit them and future generations.
- Conduct researches and scientific studies in various fields of plants, animals, insects, birds, social studies, land uses, meteorological studies, climate change, combating desertification and preserving migratory birds.
- Support community development services and motivate local communities to conserve natural resources.
- Implementing international conventions in the fields of biodiversity conservation and the proliferation of threatened species (EEAA, 2008).

### ***Cultural Heritage in El Alamein***

The city is rich in archaeological heritage of different ages and the most important monuments of El Alamein include the following (Darwish):

#### ***El Alamein War Museum***

Due to the importance of El Alamein city, a military museum was built in 1965 with the name of "El Alamein War Museum", where Germany, England and Italy participated in the information and exhibits as in the Battle of El Alamein. Thousands of foreign tourists visit the museum every year, including a collection of weapons, tanks, ammunition for the forces involved in World War II and battle progress maps.

#### ***Commonwealth Cemetery***

The graves of World War II victims are marked with annual celebrations in October each year. It is located south of the paved road in front of the El Alamein rest. It includes 7367 graveyards for victims from Britain, New Zealand, Australia, South Africa, France, India and Malaysia. There are also 11,945 soldiers whose remains have not been found. The names of some of them were written on the walls.

#### ***German cemetery***

It was built in 1959 and is located 3 km west of El Alamein city and overlooks the sea directly from a relatively high mountain with a total of 4,480 people.

#### ***Italian cemetery***

It is located 5 km west of El Alamein. It is considered the most beautiful cemetery in terms of luxury and architecture. It includes a small church, a mosque, a memorial hall, a small museum and 4,800 victims. A painting there indicates that the desert swallowed the bodies of 38,000 victims.

### **Heritage Tourism Potentials in El Alamein City**

El Alamein has many natural and cultural heritage elements that, if exploited and provided in a form that is compatible with tourism and the environment, can play an important role in promoting the development efforts of the Northwest Coast:

### *Cultural Heritage and Archaeological Tourism*

The northwestern coast is characterized by the diversity of historical places that stimulate cultural and archaeological tourism. Along the northern coast are the Allied tombs in El Alamein, the Monastery of Marmina and El Alamein War Museum.

### *Natural Heritage and Eco-tourism*

The Western Sahara is known for many environmental possibilities that attract amateur scientists and researchers. Plant species in Matruh Desert were estimated at more than 1,095 plant species, a large part of which could be exploited for medical purposes. Wild animals are numerous, although a number of them are at risk from extinction. Procedures are currently under way to announce a number of new nature reserves, as well as the existing reserves in Al-Omaid and Salum.

### **Sustainable Managing Resources for Natural and Cultural Heritage in El Alamein**

The North West Coast and specifically El Alamein city zone has many natural resources development boom for the whole region. However, the development efforts are still modest and disproportionate to the region's richness and enormous potential that can be effectively employed for economic, social and urban development. The site is located in the far north west of Egypt, and thus represents the gateway to Western Egypt and an important strategic development guide linking Egypt to the Western and North Mediterranean countries (Ministry of Planning and Administrative Reform, 2011).

The heritage areas of El Alamein are a resource of great potential and if it is used in the best ways and methods, it will contribute to support the national economy through different development plans and processes (Galal Eldin, 2012).

The general objectives of sustainable managing resources, to improve resource utilization for the development of heritage areas, can be formulated as follows (Ministry Of Housing, Utilities & Urban Development, 2007):

#### ***Improving economic performance***

- Achieving a high economic growth rate to enhance the economy in the region and enhance its absorptive capacity of employment and population.
- Integrating into the world economy by making the maximum use of its comparative advantages, competitiveness and activating international cooperation and participation agreements.
- Providing new jobs in a variety of economic activities capable of sustained growth.
- Increase the exploitation of resources, taking into consideration the requirements of sustainability through conservation and rationalization of what is exploited (agricultural lands, water and urban areas), exploration and exploitation of untapped resources (reclamation lands, groundwater and mines).

#### ***Improving Social Conditions and Encouraging the Involvement in Community Work***

- Provide social, cultural, health and education services nearby urban communities, achieving the fairness of distribution.
- develop different types of new urban communities that are consistent with the nature of the region and provide a safe and stable life for the population.
- Develop human skill on trades and activities that contribute to the advancement of Bedouin communities.



-Activate the participation of local communities in the efforts of economic and social development.

- Focus on human development through training, education and health programs and disseminating them among children, youth and females within local communities through the selection and provision of new environmentally, socially and economically compatible technologies.

### ***Infrastructure Development***

- Strengthening the functional connection of the study area to other regions of the country through the development of regional infrastructure networks to promote relations in various fields.

-Establishing an integrated land, sea and air transportation networks linking the urban areas with the main centers and linking the region internationally, thus contributing to strengthening the interconnections with the global economy.

-Increase the ease of access and transition between different urban areas (existing communities and new ones whose resources have not yet been exploited), and the other regions at national, regional and global levels.

### ***Sustainable Development and Conservation of Natural and Cultural Resources***

- Environmental upgrading and conservation of natural resources to ensure that the development processes continue and maximize their benefits.

- Preserving the cultural and social heritage of Bedouin communities and promoting environmental crafts and products.

- Environmental impact assessment follow-up of different development activities.

- Re-distribution of the population away from the existing heritage areas and agricultural land.

- Optimal exploitation of natural resources and conservation of water resources and rational use of these important resources, especially in the new reclamation areas.

### ***Promoting the Organizations Supporting the Implementation of the Development Plan***

- Emphasize the commitment of governmental organizations to support development and supervision guidance.

- Forming an independent entity to manage, review and implement development plans.

- Encourage the participation of the private sector and NGOs in the development efforts.

- Developing the scientific and applied research in the fields of desert communities' development.

In order to achieve the above objectives, it is imperative that the urban plan properly deal with the available land and water resources in the development zone, ensuring that the region's potential is exploited while ensuring the preservation of non-renewable resources and emphasizing the importance of providing long-term expansion and development opportunities for future generations.

## **Findings: Managerial Guides and Sustainable Development Principles of the Heritage Tourism Industry Resources**

Findings of this paper took the form of managerial guides and sustainable development principles of the heritage tourism industry resources. Hereby, the objectives, actions and

potential implementation parties were mentioned. Table 1 shows the managerial guides and sustainable development principles of the heritage tourism industry resources.

Table 1. Managerial Guides and Sustainable Development Principles of the Heritage Tourism Industry Resources  
Source: The Author

Objectives	Actions	Potential Implementation Parties	
<ul style="list-style-type: none"> <li>. Bring investment.</li> <li>. Training and qualifying human resources in the local community.</li> <li>. Marketing of heritage villages.</li> </ul>	<ul style="list-style-type: none"> <li>. Participate in the development studies of heritage areas.</li> <li>. Implementation of some tourist activities and events.</li> <li>. Follow up implementation and coordinate the roles of the participating parties.</li> </ul>	<i>Ministry of Antiquities</i>	Governmental Sector
<ul style="list-style-type: none"> <li>. Contribute to the development of heritage areas through productive programs and social development centers.</li> </ul>	<ul style="list-style-type: none"> <li>. Cooperative societies for the development of heritage areas . .</li> <li>. Contribute to the implementation of training and awareness programs for residents of heritage areas in coordination with the General Authority for Tourism.</li> </ul>	<i>The Ministry of Social Solidarity</i>	
<ul style="list-style-type: none"> <li>. Develop and improve the entrances and transportation of heritage areas.</li> </ul>	<ul style="list-style-type: none"> <li>. Delivery and maintenance of roads for heritage areas.</li> <li>. Include the names of the heritage areas within the road signs.</li> </ul>	<i>Ministry of Transportation</i>	
<ul style="list-style-type: none"> <li>. Reclamation of farms near heritage areas.</li> </ul>	<ul style="list-style-type: none"> <li>. Support and raise awareness of farmers and encourage them to produce traditional agricultural crops.</li> </ul>	<i>Ministry Of Agriculture</i>	
<ul style="list-style-type: none"> <li>. The delivery of electricity and water to the villages surrounding the heritage areas.</li> </ul>	<ul style="list-style-type: none"> <li>. Implement the water and sewage networks within the areas to be developed.</li> </ul>	<i>Ministry of Water and Electricity</i>	
<ul style="list-style-type: none"> <li>. Provision of telecommunication services.</li> </ul>		<i>Communications Commission</i>	
<ul style="list-style-type: none"> <li>. Implement and manage investment projects in heritage areas.</li> </ul>	<ul style="list-style-type: none"> <li>. Distributing tourism investments in different regions and taking advantage of tourist</li> </ul>	NGOs	Private Sector

	potentials and facilities, taking into account the lack of focus on the main cities only, as this may put pressure on the infrastructure		
. Marketing sustainable tourism projects to reach the largest number of target audience.	.Provide the necessary infrastructure for the development of eco-tourism by establishing hotels, restaurants, amusement parks and facilities for sports facilities.	NGOs	
. Contribute to the awareness of the community of the economic benefits that can be obtained as a result of the application of the principles of sustainable tourism development and protection of natural resources			Local Community
. Technical training of the local community necessary for the process of heritage tourism in the sites			
.Implementing small projects in the field of local products and selling them. . Support for the financing of the development of heritage areas	.Participation in the management of heritage areas. Implementation of tourism programs and activities. . Participation in financing development and rehabilitation programs.		

The proposed development guides and principles of the heritage tourism industry resources are based on linking economic development projects with social and urban development, redistributing the balanced population according to the available resources and establishing population attractions by allocating some appropriate activities to the desired heritage area, with the aim of achieving coordination and integration between economic, social activities, urban and environmental resources.

The following Figure 3 summarizes the three dimensions of the development principles:

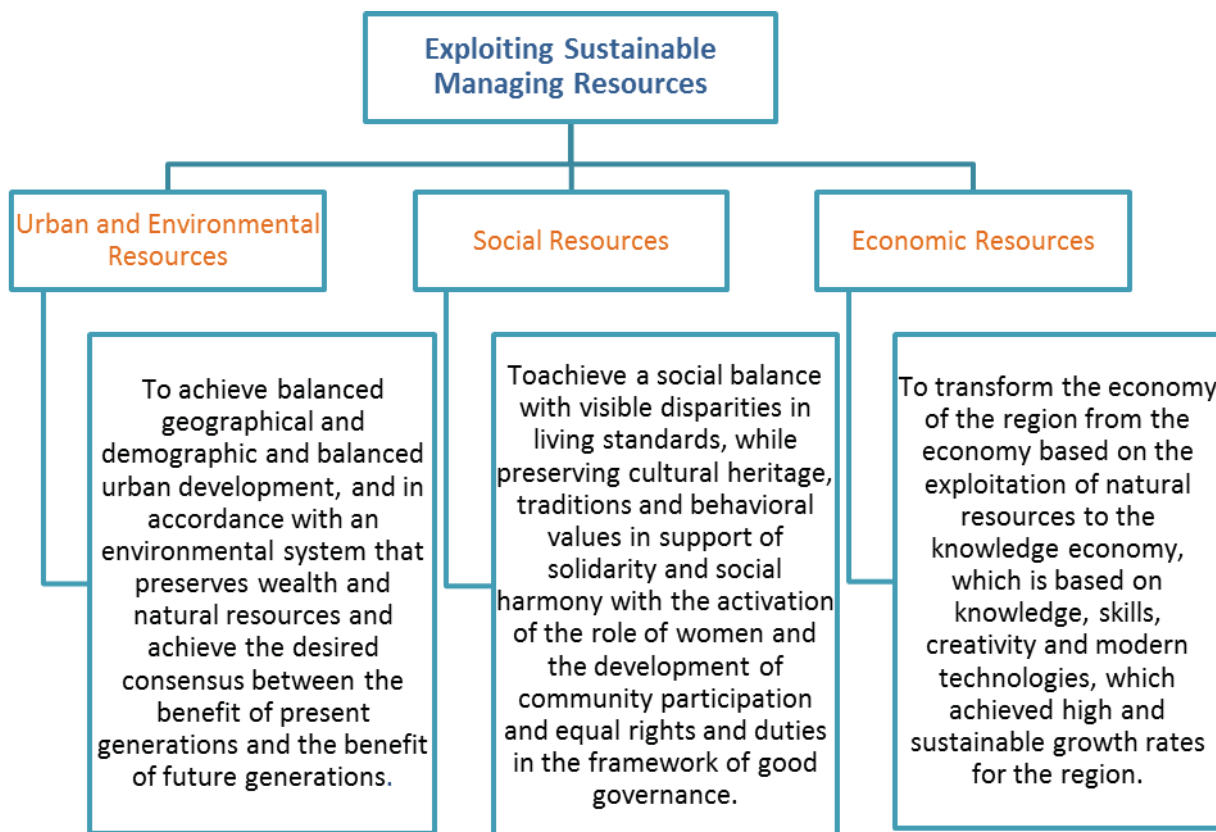


Figure 3. Three Dimensions of the Development Principles  
Source: The Author

## Conclusions

The aim of this paper was to analyze resources which have a better implementation in managing the sustainability in tourism destinations and in El Alamein as a final objective. Based on the discussion and findings of this paper the author was able to extract the following:

The comprehensive development strategy of El Alamein city focuses on linking its development with the rest of the Republic's regions, thus effectively contributing the economic growth at the national level. This regional linkage can maximize the aggregate benefit and the effectiveness of local development efforts, through:

First: the integration of different tourist attractions elements in El Alamein city and the western desert, so that the tourism product intertwines between beach tourism, water sports tourism on the coast and sports tourism in the south, military tourism (graves and museums of the Second World War), and religious tourism (Monastery of Marmina), and environmental tourism (Al-Omaid nature reserve).

Second: Providing the commercial, service and recreational elements that have become as important as the tourist villages, as the demand on integrated services villages is much higher compared to other villages that lack some of them.

Third: The external orientation to benefit from the elements of the North West Coast region in the development of economic activities with export potential, as this approach provides broad prospects for economic growth.

As for tourism sector specifically, the elements of the development strategy are:

- Development of comprehensive resorts designed to receive international tourism throughout the year.
- Connecting beach resorts with safari tourism and eco-tourism in the western desert.
- Development of nature reserves tourism (Al-Omaid nature reserve).
- Development of handicrafts and household industries for international tourism.

Hereby, the paper has partially fulfilled its aims by exploring the potentials of exploiting sustainable managing resources for heritage tourism. However, shortcomings of the current research, which may include future areas of investigation, are other real case studies and further research to achieve sustainable tourism of built heritage in all developing countries which lack enough funds and expertise for such noble purpose. The leading developed countries could give an anchor to such countries with poor financial resources to achieve efficient management of their scarce heritage, while exploring the application of such innovative processes in different contexts in the meanwhile.

## References

- Boswell, R. & O’Kane, D. (2011). *“Introduction: heritage management and tourism in Africa”*. Journal of Contemporary African Studies, Vol. 29, No. 4, pp. 361-369.
- Croft, T., (1994). *“What Price Access? Visitor Impact on Heritage in Trust”*. Cultural Tourism, ed. J. M. Fladmark. London: Donhead Publishing
- Darwish, M., *“Matrouh Western Egypt Gate”*, Bibliotheca Alexandrina.
- Dolgorsüren, J. (2004). *“Cultural Tourism Survey Report”*. International Conference: Building Partnerships in Cultural Tourism, Ulaanbaatar, Mongolia. pp. 9-12.
- Douglas, N. & Derrett, R. (2001). *“Special Interest Tourism”*. John Wiley & Sons, Australia. pp. 154-158.
- EEAA, Ministry of State for Environmental Affairs. (2008). *“Environmental profile of Matrouh Governorate”*, Environmental Affairs Department.
- EEAA, Ministry of State for Environmental Affairs. (2008). *“Report of Nature Reserve, Nature Protection Sector”*, Environmental Affairs Agency.
- Galal Eldin, A. (2012). *“Towards a Methodology for the Development of Egyptian Coastal Regions through the Economic Multiplicity of their Coastal Cities”*. PhD Thesis, Faculty of Engineering, Cairo University, 2012.
- Hughes, M., & Carlsen, J. (2010). *“The business of cultural heritage tourism: Critical success factors”*. Journal of Heritage Tourism, 5(1), 17-32. doi: 10.1080/17438730903469805.
- ICOMOS (1999). [www.icomos.org/tourism/charter.html](http://www.icomos.org/tourism/charter.html).
- Leask, A. and P. Goulding, (1996). *“What Price our Heritage? A Study of the Role and Contribution of Revenue Management in Scotland's Heritage Based Visitor Attractions”*. Managing Cultural Resources for the Tourist, ed. M. Robinson., N. Evans., and P. Callaghan. Sunderland: Business Education Publishers.
- Lindberg, K., Molstad, A., Hakins, D. and Jamieson, W. (1999). *“Sustainable Tourism and Cultural Heritage: A Review of Development Assistance and its Potential to Promote Sustainability”*. New York: NWHO. Retrieved from [http://www.nwhf.no/files/File/culture\\_fulltext.pdf](http://www.nwhf.no/files/File/culture_fulltext.pdf).
- Loulanski, T. & Loulanski, V. (2011). *“The sustainable integration of cultural heritage and tourism: a meta-study”*. Journal of Sustainable Tourism, Vol. 19, No. 7, pp. 837–862.
- May, V., (1991). *“Tourism, environment and development – Values, sustainability and stewardship”*. Tourism Management, 12(2):112-124.



Ministry of Housing, Utilities and Urban Development. (2007). *"Executive Summary of the Strategic Plan for the Development of the North West Coast and the Desert Deer"*, Final Report, General Authority for Urban Planning.

Ministry of Planning, Follow-up and Administrative Reform (2011). *"Update of the Comprehensive Development Strategy and Plan for the North West Coast and Desert Deer (2010-2032)"*.

Nash, D. and R. Butler, (1990). *"Towards sustainable tourism"*. Tourism Management, 11(3): 263-264.

Nasser, N. (2003). *"Planning for urban heritage places: Reconciling conservation, tourism, and sustainable development"*. Journal of Planning Literature, 17(4), 467-479. doi: 10.1177/0885412203017004001.

Novelli, M. (2015). *"Tourism and Development in Sub-Saharan Africa"*. Abingdon: Routledge.

Qajja, M. (2005). *"Modernity and Heritage"*. article, Journal of the literary position, No. 414, Syria.

OECD (2010). *"Culture and Tourism"*. <http://www.oecd.org/document/html>.

Saarinen, J. & Rogerson, C.M. (2015). *"Setting Cultural Tourism in Southern Africa"*. Nordic Journal of African Studies, Vol. 24, Nos. 3&4, pp. 207–220.

Sustainable Tourism Online. *"Dimensions of Sustainable Tourism"*. 2017 [cited 2017; Available from: [http://www.sustainabletourisonline.com/awms/Upload/Images/Content%20Images/destn2\\_envirn.jpg](http://www.sustainabletourisonline.com/awms/Upload/Images/Content%20Images/destn2_envirn.jpg).

Timothy, J., & Nyaupane, G. (2009). *"Cultural Heritage and Tourism in the Developing World: A Regional Perspective"*. Contemporary Geographies of Leisure, Tourism and Mobility Series. Oxford: Routledge. Timothy.

UNEP (United Nations Environment Programme) (2005). *"Forging Links between Protected Areas and the Tourism Sector, How Tourism Can Benefit Conservation"*. Paris: UNEP.

UNESCO (1972). *"Convention for the Protection of the World Cultural and Natural Heritage"*. General Conference, 17th Session, 16 November 1972, Paris.

UNWTO, Tourism Highlight. 1996: Madrid, Spain.

WTO (2009). [https://www.wto.org/english/res\\_e/booksp\\_e/anrep\\_e/anrep09\\_e.pdf](https://www.wto.org/english/res_e/booksp_e/anrep_e/anrep09_e.pdf).

# The Dilemma of Public Spaces in Cairo: A New Model Investigation Tool

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**Abstract:** What is the essence of a “public space”? A public place is a space made meaningful and it is governed by the specific social norms that produce it. Long ago, urban spaces, such as the Agora, emphasized a unique affinity for a society’s state of well-being. It represented a democratic situation that enabled people to exercise marketing and social activities freely. Nowadays, the definition for a public space has changed! The squares and open spaces have become inherently political and a window to show a nation’s political state and government that was influenced by the concept of globalization and liberal values. Cairo exhibits an ample amount of forms of public places: extending from the physical places as large gardens and open spaces to other ones such as streets, communal enclosed space and even more. Sometimes the government and private officials have control over the activity and ownership of the place. Similarly, a public space could be affected by design, on a macro and micro scale level, and by social and cultural norms.

What are the factors that make and control a public space? The first purpose of this research paper is to develop a solid theoretical standard of publicness as a practical tool: a model for assessing public places. Five key dimensions of public spaces have been presented and differentiated: Ownership, Design, Animation, Civility, and Control. Through their synergic interaction, where the sum of all is greater than the parts added together, they create the publicness of public space. The second aim is to translate the assessment model into to a practical methodological tool to define, understand, and compare public spaces. Different and contemporary typologies of public spaces throughout Cairo was examined and compared. Case studies included Al-Azhar Park, Asr Al-Shamee’, and Cairo Festival Mall.

**Keywords:** Public Spaces, Cairo, Ownership, Design, Civility, Control, Animation

## Introduction

All we see and seem is but a dream within a dream! In order to construct music, we need silence to cut it and to formulate its beats. In the same manner, in order to construct our reality, we need space to define its different "realities" in between; a space that is a product of many variables and dimensions. Throughout the daily life routine in Cairo, a diverse, interesting amalgam of public spaces exists. To a certain degree, urban public spaces such as squares and plazas are where the city’s residents congregate and interact with one another, and where the city’s visitors and tourists come to observe local customs. Even under authoritarian regimes in a special place such as Cairo, urban places such as these often symbolize the heart of a city, perhaps even the nation, and are the heartbeat of its people, as well. Beyond ideology and politics, in these places one can sense the vibrancy of a culture and feel its energy.

## Research Objectives and Approach

Is there something that resembles a “Utopian” public space? A public place is considered the most public, from the point of view of ownership, when it is owned by a public body, democratically elected. The most commonplace example given in the academia as an “ideal public place” is the Greek Agora. It is crucial to highlight that the agora is often considered a legendary ideal of public space because of the Athenian democracy that created it. The Agora was mainly considered a place of free speech and a market place in which people could easily interact. Today, our societies are far from the Athenian representation democracy to take place and therefore it is asserted that if a public place is

owned by a publicly accountable body, democratically elected, then it is as close as possible to the Athenian ideal.

“Space is not a scientific object removed from ideology or politics. It has always been political and strategic. There is an ideology of space. Because space, which seems homogeneous, which appears as a whole in its objectivity, in its pure form, such as we determine it, is a social product.” Henri Lefebvre.

Sociologist Henri Lefebvre is credited with introducing the idea that space is socially produced. His analysis includes a historical reading of how spatial experience has changed over time depending upon social circumstances and this is the main building block of any public space. Henri Lefebvre in his book, *The Production of Space*, highlighted the three dimensions of activating a public space: the lived, the conceived, and the perceived. He also stated that public spaces aren't absolute; instead, they are always in flux and changing; a flux that results from a multitude of factors including accessibility, ownership, design, control, functions, and social behavior. This research aims to explore and gather different multi-disciplinary conceptualizations of public space, under one inclusive and as objective as possible to formulate a Model -Investigation Tool that describes, analyzes, and illustrates the “publicness” of a public place.

### **Literary Reviews: Recent Evolution of Public Space Researches**

Public space research is a fairly recent and widely known area of investigation. Public place and urban spaces have been studied previously in a varied and mostly disparate fashion. For the past century, publication such as the famous writings of William H Whyte *Whyte's Securing Open Space for Urban America: Conservation Easements* (1959) and Jane Jacobs' *The Death and Life of Great American Cities* (1961) had a rich view on public spaces and how it flourished. In 1969, while working with the New York City Planning Commission, Whyte began to wonder how newly planned city spaces were actually working out – something that no one had previously researched. This curiosity led to the *Street Life Project*, a pioneering study of pedestrian behaviour and city dynamics. On the other hand, Lyn H. Lofland, a professor and chair, Department of Sociology, University of California, particularly highlights the overwhelming meaning of the public realm and its connection to social and psychological factors. *The Production of Space* by Henri Lefebvre highlighted that space is lived, the conceived, and the perceived. Similarly, Gaston Bachelard, in *The Poetics of Space*, explained the social and psychological process of internal consciousness to emotional experience to the formation of space.

Throughout time, there has been a growing concern with a public space's quality. It seems that something is changing in the nature of urban public places around the world. Public spaces no longer harboured some descent urban qualities for people, thus leading to the misuse or undermine of their potential. As a result several books, such as Francis Tibbald's *Making People Friendly Towns*, have been written to lessen these effects by introducing new elements for redesigning the public realm. Furthermore, a lot of national studies governing the sociological, philosophical, and design aspects of public spaces in Cairo have been produced. In Egypt, as public spaces have been decreasing in value and demand, constant “revolutions” is occurring by the people to recapture the essence of such places. Singerman and Amar, in *Cairo Cosmopolitan* (2006), highlighted that Cairenes re-emerged as citizens, bearing the mantle of public status, sovereignty, legality, and legitimacy. And, crucially, by claiming to redefine questions of democracy, legality, and social justice on the streets of the city, the people of Cairo claimed a certain kind of

cosmopolitan status after certain national problems such as poverty, capitalism, privatization, and the poor economic status ; a transitional agency that reshaped and defined public spaces nowadays.

On another aspect, many respected scholars have reshaped assessment models that dealt with different characteristics of public spaces. In 2007, two authors from the USA, Jeremy Nemeth and Stephen Schmidt, looked at the design, use, and management aspects of public space and attempted to create an evaluation. Also in 2007, another model was proposed by UK's CABE was called the "Spaceshaper" and was defined as "a practical toolkit that could be used by everyone in order to measure the quality of a public place. Nevertheless, a public space is always in flux and changing. Previous approaches of the two toolkits translated the methodology into numerical values that can't accurately explain the characteristics of public spaces. It can be argued that the particularities of a public place are lost when its publicness is translated into numbers. Each public place has its own identity, its own atmosphere or "sense of place" and "attributes"; instead, this paper focuses more on attributes and indicators to set different levels of publicness through main dimensions.

### **The Dilemma, Public Spaces in Cairo and Dimensions Raised into Question**

Many factors such as accessibility, control, maintenance, image, ownership, and design has a direct relation to a public space well-being and thus the hypothesis of this paper is to create an understanding as a linking process of all of these factors and to highlight on their synergetic connections.

**Different Typologies.** While thinking of different typologies of public spaces, one could quickly identify parks and gardens as places for social interaction. People head to those destinations to enjoy their time with their families and beloved ones. Other could identify streets as the main public spaces cities can offer. Similarly, but on a more different level, in 1999 Kim Dovey, an Australian architect, highlighted that one of the key phenomena of the late twentieth century, however, has been the production of pseudo-diversity within privatized quasi-public space. The shopping mall emerged as a new public space.

**Location.** Places that are strategically well-located in a strong urban setting (those with centrality and connectivity) within a city's movement pattern have greater potential movement and thus greater potential for different social groups coming together in space and time. Al-Azhar Park, one of Cairo's most prestigious and well-known garden, is located centrally near the historic Islamic Cairo; consequently, its accessibility is directly feasible to its geographic status.

**Maintenance.** Through different site visits, it was seen that some parks, such as Asr El-Shame', was less maintained regarding its softscapes than Al-Azhar Park. This could hypothesis as miss-use of people, or an under management of the authorities in the park.

**Accessibility.** When arriving to a public space the first question to ask is: "How could I enter?" Is it free for all categories of people? This problem arises in many public spaces such as malls and parks throughout Cairo; such open spaces tend to be fences and uphold a certain fee from people to enter. These acts prohibit the use of some parks, while other parks offer free pass and allows accessibility and most importantly diversity. So is this a character to be used in the new model of investigation?

**Control.** Zeinab Khatun, in figure 1, is an important historical building that lies in Old, Islamic Cairo. It holds a deep memory and belonging towards Cairene people. The Image above (left) shows the square in front of the building as a communal gathering and mostly plays the role of a parking space during 2010. By 2015 the square was transformed into a

pleasant and outdoor experience for Tekiyt Khan Khatun café and restaurant. Is this transformation formally leased by the owner of the restaurant toward the government? Or is it another kind of “encroachment phenomena”?



Figure 1. Zeinab Khatun Square: Left (taken in 2010), Right (taken in 2015). Courtesy of Author.

**Image and Memory.** As highlighted above the square is widely known by Cairene people as an intimate location to head during the weekdays or the weekends to enjoy a good eat in the interesting historical background. If the place wasn't situated in this exact location, it would not have been a target for a wide variety of users.



Figure 2. Sidewalks of Downtown Cairo. Courtesy of Author.

**Responsible Freedom and Control.** Public streets are among cities' greatest assets. The streets provide not only the transportation, but the vitality, attraction, and interaction in a city. As a pedestrian strolls through these streets, he or she finds different forms of obstructions; encroachment techniques by people to privatize and uphold a place for their own will. Although this isn't necessarily a negative thing but public good should be raised into question and a complementary method of control among the authorities and people could take place.

**Physical Design.** Another important element raised into question is the civility and to which extent it provides users a secured and descent environment. As Henri Lefebvre have said, the physical spaces occurs in three different perspectives: the conceived, space by designers, the perceived, space seen by the people, and the lived, space that results from people social interaction. The physical disposition and design of a public place should always be put into question.

Many factors such as accessibility, control, maintenance, image, ownership, and design has a direct relation to a public space well-being and thus the hypothesis of this thesis is to create an understanding as a linking process of all of these factors and to highlight on their synergetic connections.



## **Modelling the Five Main Dimensions of Public Spaces**

### ***Space vs place***

Defining these terms “place” or “space” is crucial before categorizing the five main thematic dimensions in this research’s model-investigation tool. “Place” and “space” are often described as “slippery” words. Space has been conceptualized in a rather more philosophic and scientific way than place. For Lefebvre, the production of space specifically focuses on “social space.” In this way, space serves to reflect the cultural values that result from the practice of producing social space. In his work, all public forums reflect the production of social space to some degree and the dominant values of their cultures can be deduced from analysis of that space. From such analyses, public forums are treated primarily as particular places that result from the production of social space. On the other hand, Michel de Certeau, a French scholar of philosophical and social sciences, stated that space is a “frequent” place, and an intersection of moving bodies: it is the pedestrians who transform a street (geometrically defined as a place by town planners) into a space. Place is defined here as an assembly of elements coexisting in a certain order and the space as animation of these places by the motion of a moving bodies.

Although this distinction between “place” and “space” is only a logical way of putting meaning logically into things, the meanings of them are often more open and infinite, varying from person to person, from context to context and situation to situation ranging from objective and subjective reasons. Nevertheless in this paper, their definition will be subjective. The Arabic term of Space is called "فراغ" or better defined as a geometrical void with only three dimensions. In contrast a place is defined in Arabic as "مكان" which is a venue or a place. A specific place is defined by a specific entities or object that governs it so in that sense a place is made more meaningful and complex than a space. After conceptualizing the difference between “place” and “space”, the term “public space” will be given to an abstract level of conceptualization. In order to formulate the new assessment model, it will be hypothesised that a public “place” is the meaningful outer boundary of the model while the public “space” as the marginal, interior borderline. (see figure3).

### ***The Five Dimensions of Analysis and Model***

Due to a lack of clarity from the part of many authors but also to the recent emergence of the field of public space research, a clear and cross-disciplinary definition on a wholistic view for public space assessment could not be found. What was found instead was a wide variety of definitions and terms. When closely analyzing the different ways of defining and conceptualizing public space, it can be noticed that the literature can be grouped in five thematic dimensions.

The new model is based on three entities: the main five dimensions, their basic assessment characteristics, and the indicator levelling. Figure 3 shows all the 3 entities with two basic extremes: public space (inward) and public place (outward). The first entity are the five main dimensions. These dimensions highlight the tangible and intangible aspects of P.S's. These five themes are: Ownership, Design, Civility, Control, and Animation. The second entity is the main assessment characteristics as highlighted above. Each dimension has its own characteristics and accordingly each of which has its indicator levels. The third and final entities are the indicator levels. As the indicator levels goes inward toward the center of the circle, the less public a space could be, and as it goes further from the center and according to the “public place line”, publicness increases.

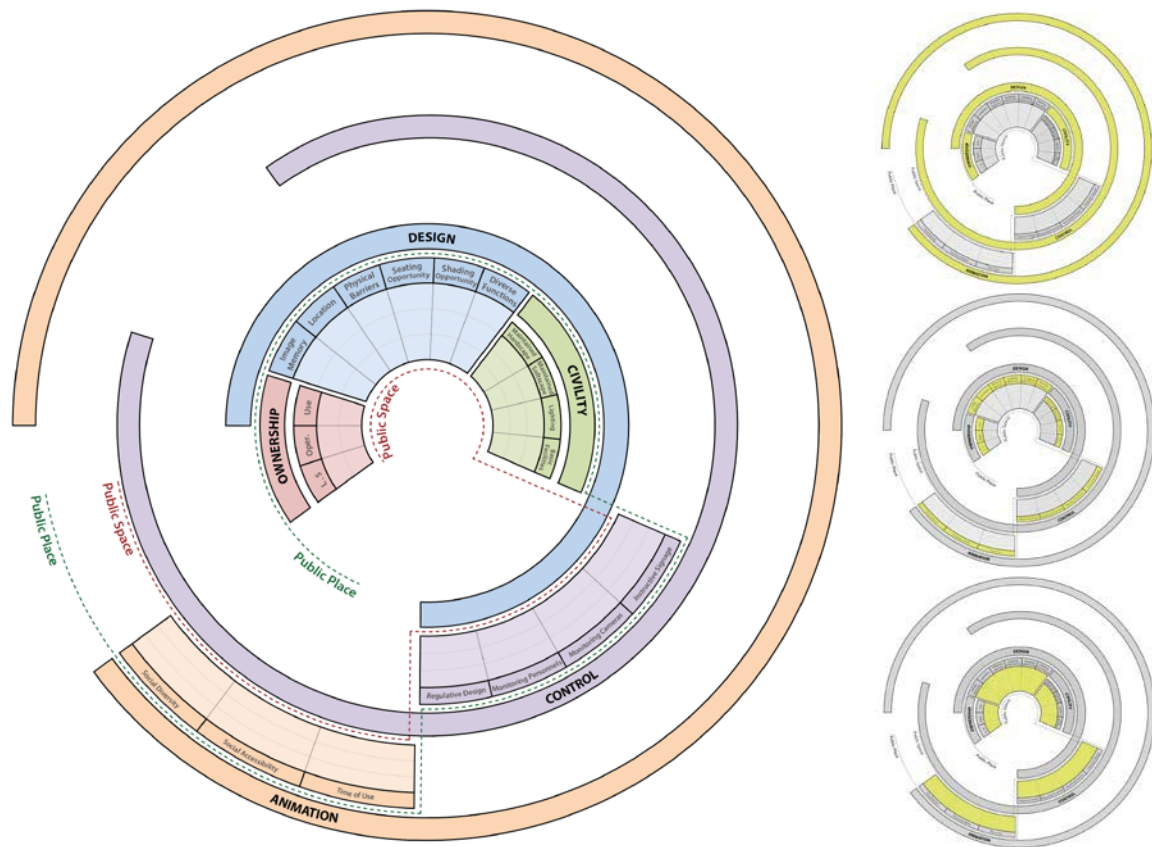


Figure 3. Public Space Assessment Model. Dimensions (top right), Assessment Characteristics (middle right), Indicator levels (bottom right). Courtesy of Author.

#### *Model: Ownership Index*

First, a key characteristic of public space appears to be related to the ownership and legal status of a public place. Lofland (1980) identified a crucial element for a place's publicness, its maintaining in public ownership. As shown in figure 4, ownership is investigated by 3 characteristics: its legal state, activity, and usage. It lies between such extremes along which there are combinations of the three characteristics. The more public situation is when a site is owned by a public body mandated to act in the public/collective interest and accountable to elected representatives of the community, thus the more level of publicness a place achieves. Such examples may include:

- Public Legal state – Publicly operated - Public used (ex: street, square).
- Private Legal state – Publicly operated - Public used (ex: airports, bus stations).
- Private Legal state – Privately operated - Public used (ex: shops, cafes, bars, restaurants).
- Private Legal state – Privately operated - Privately used (ex: internal communal courtyard of a house block).

#### *Model: Design Index*

The second distinct theme that is crucial to understand public places is their physical disposition, Design. Identifying a place's physical disposition can be identified on two scales: the macro-scale approach and the micro-scale approach. The macro-scale approach relates to what the public space holds upon the user and its connection to the physical urban settings. Every P.S is part of something greater in its physical environment. The degree of publicness is influenced by its strategic location, boundaries, and connectivity to the city.

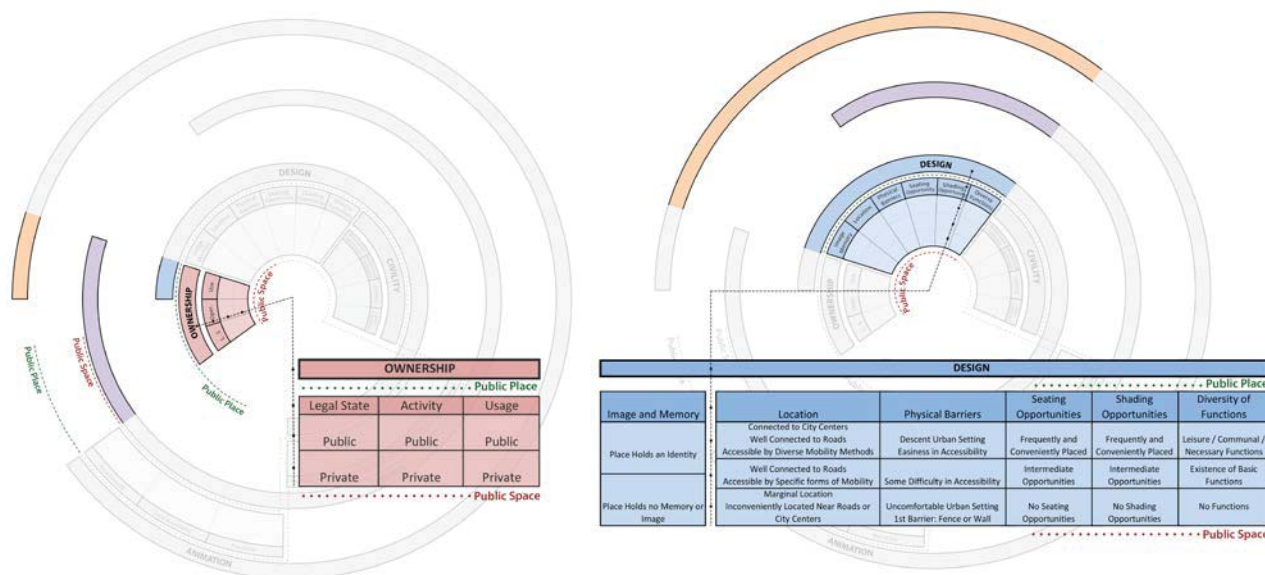


Figure 4. Public Space assessment model: Ownership and Design Index. Courtesy of Author.

There are 3 basic qualities that are defined on a macro-scale level as shown in the figure above are: Image and Memory, Location, and Physical Barriers. In terms of micro-design, places should be designed intimately in order to support the different needs of people in public space. These have been identified by Carr et al. (1992) as “passive engagement”, “active engagement”, “discovery”, “comfort” and “relaxation”. In the authors’ words, these “must be given concrete expression by the designer in a particular social and physical context. Although the social and physical context varies from location to location, resulting in each public place having its own identity and character, there is a consensus that for a variety of “optional” and “social” activities (Gehl, 1996) to happen, two key prerequisites should be met in the design of a public place: good opportunities for sitting and good opportunities for walking in addition to diversity of functions.

The “more public” situation regarding macro-design, the more it is being central and well-connected with potential for plenty of accessibility by different groups with diverse mobility methods. There are no explicit thresholds, such as hindering gates and fences. In terms of micro-design, it refers how the design of a public place supports and encourages animation, when there are different opportunities for sitting, walking or actively engaging with the environment.

#### Model: Civility Index

The third theme is concerned with the maintenance of public places according to certain social standards, so that they are clean, friendly and inviting areas. It also includes the different facilities and provisions that should be present to evoke a humane environment. Many of the reviewed writings identify the presence of refuse and decay in urban public places as a cause and a mark of the broader decline of the urban public realm.

The “more public” situation corresponds to an environment that looks pristine, tidy, in a good state of repair, with well-maintained greenery and hardscapes. Nevertheless, the quality and amount of lighting at night can influence a site’s publicness, especially those public places that are meant to be used on a 24 hour basis. A key element included in civility is the presence of public toilets. The “less public” situations include the under-management of the place and the lack of provisions for lighting and basic functions.

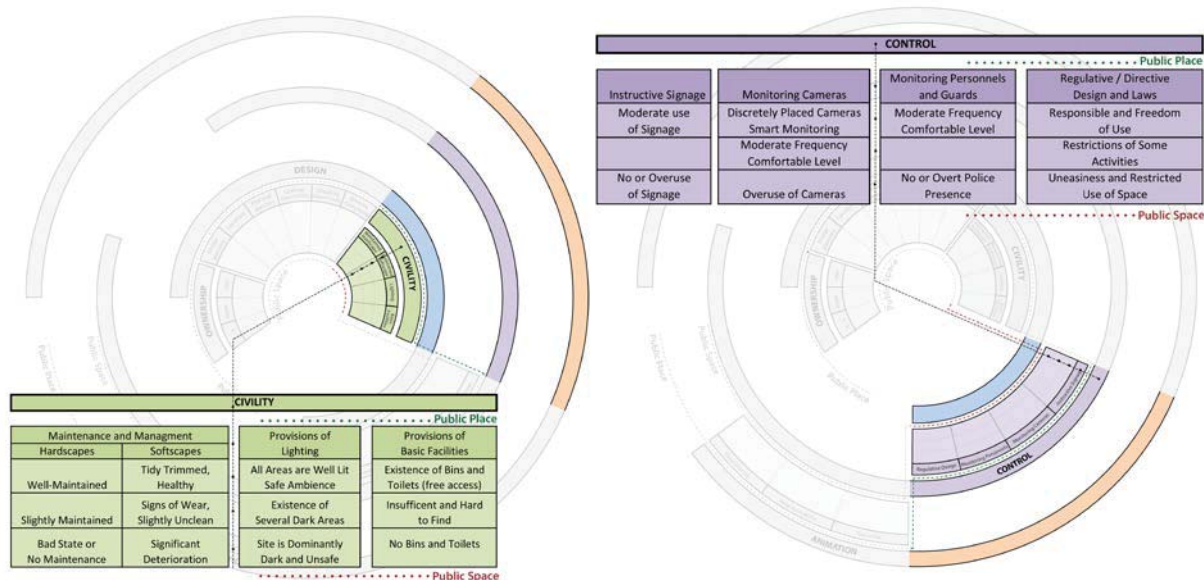


Figure 5. Public Space assessment model: Civility and Control Index. Courtesy of Author.

### Model: Control Index

A fourth strand of research is related to public space as the arena where the fragile relation between freedom and control unfolds. Many authors, among which Carr et al. (1992) and the North American academics Mitchell (2003), Goodsell (2003) or Mensch (2000) consider the quality of a public place of being a democratic arena for public life as fundamental for its publicness. As a result, they are the places where fundamental rights guaranteed by a democratic society, such as the right to speak freely and assemble, are manifested. What appears to have happened nowadays is an increase in the surveillance and control measures in public space. Nevertheless a common ground should be achieved between the control of a space and the responsible freedom of act for people. Management techniques range from including features that encourage freedom of use, access, and behaviour (such as making seating available) to providing elements that discourage use and control access and behaviour, such as the excessive presence of panning surveillance cameras or armed security guards. The level of control can occur on two levels: Active control, the comfortable presence of guards and police, and passive, the moderate use of signage, cameral and law systems.

### Model: Animation Index

The different and final strand index of the research comes mainly from the sociological and anthropological public space literature and refers to the use of public space, or in other words, to their animation, the fifth dimension. Being the places of free assembly and interaction among the members of a community, public places are the physical stage where "...the functional and ritual activities that bind a community, whether in the normal routines of daily life or in periodic festivities" The use of public space is directly related to the "who" and "whom" the place is used and during which times: Social accessibility and diversity (figure 6). In addition, the "more public" situation in terms of animation highlights the constant time of use and to the availability of a high diversity of users, engaged in a wide variety of activities through design.



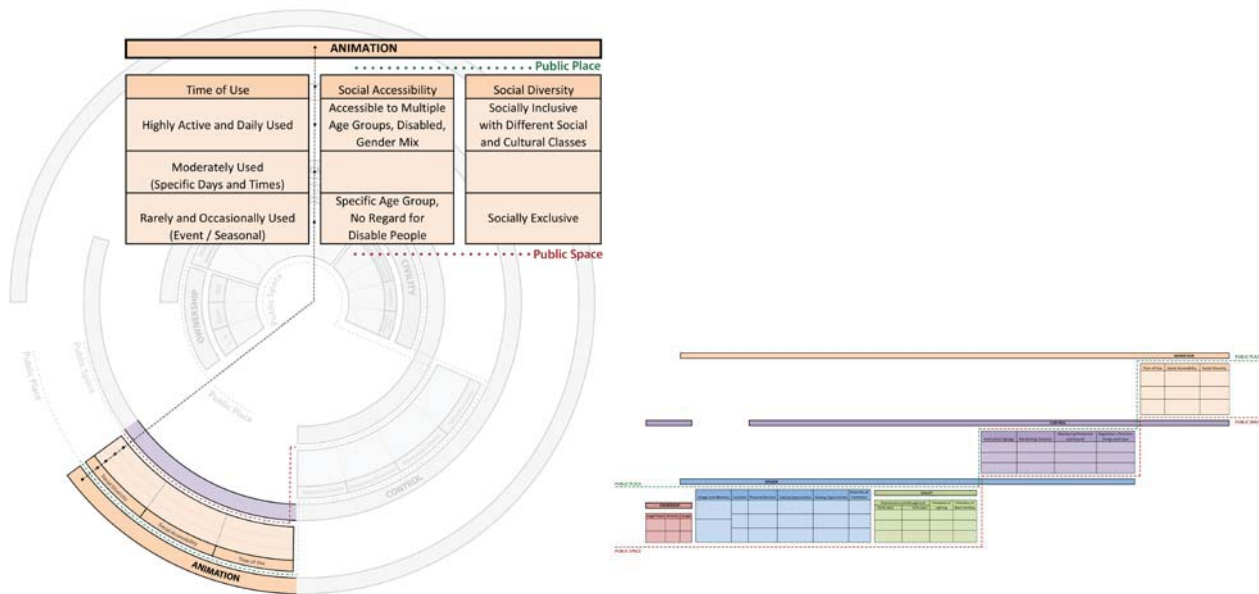


Figure 6. Public Space assessment model: Animation Index (left) and the Model Unfolded (right). Courtesy of Author.

According to the previous perspectives, the dimensions will always overlap and work together. Figure 6 unfolds the model into a visual representation. This representation highlights that there are no hierarchy; instead, they influence and can be influenced by another dimensions. For example, in addition to its three characteristics in Animation, this social dimension is determined and affected by all the remaining four counterparts. It represents Lefebvre's lived space in which aspects of control and power, design implementations, and the ownership state affects the degree of publicness. On the other hand, the dimension's characteristics of Control such as signage, and control decisions is considered to be part of the design decisions and ownership factors of a public space. In the same case, this dimension is interrelated with the social animation and how people could use a space freely or hindered by specific control and design factors.

### Modelling Public Spaces and Case Studies

After introducing the model, this part of this paper is dedicated to the practical application of the model using the five dimensions. Three case studies were selected to apply the model and investigate the publicness rating obtained: Al-Azhar Park, Asr El-Shamee Garden, and Cairo Festival City Mall. The selection criteria is to provide a wide array to compare between not only different forms of public spaces, but also the same kind of public parks in which different characteristics were observed. Although the two parks are located in unique urban settings their areas differ dramatically and the question arises whether area is another factor to affect public spaces or not. Nevertheless, these typologies of public spaces have varied opportunities for different indicator levels. Most information is obtained through qualitative and quantitative measures: objective photography documentation, scientific observations, and short interviews.

#### Case Study: Al-Azhar Park

According to the index indicated in figure 7, the Park's ownership state indicates the legal state originally by Aga Khan who leased the park to the public yet the government operated it for public use. Design indicators were found on the macro and micro scales of the park; ranging from a multitude of characteristics: the strategic and historical location,



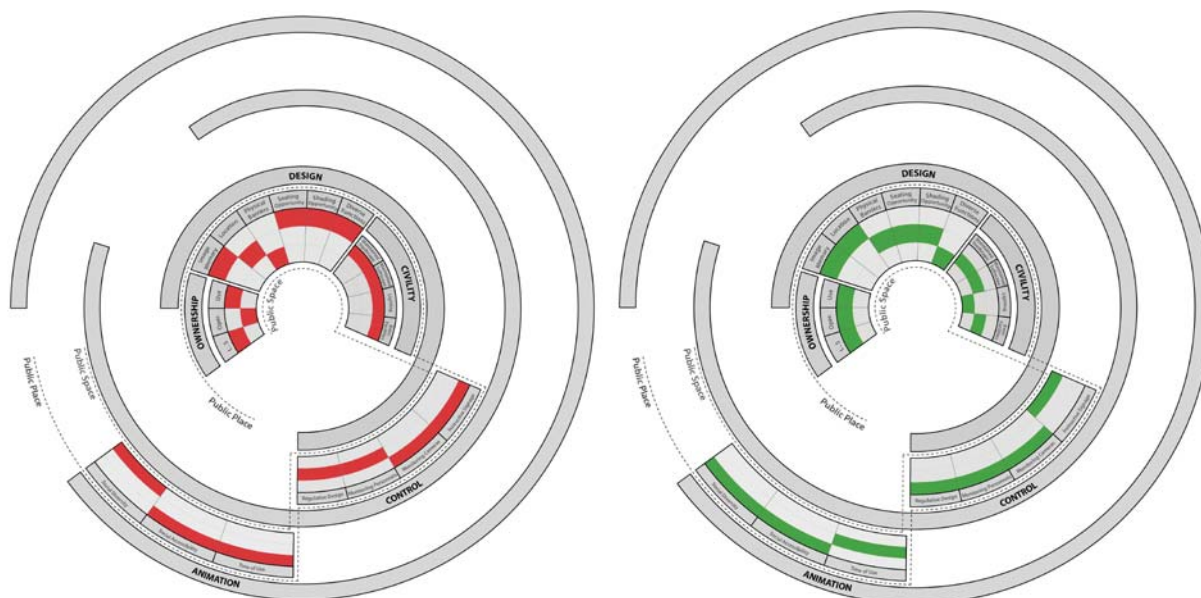


Figure 7. Model Index for Al-Azhar Park (left). Model Index for Asr El-Shamee (right). Courtesy of Author.

the hindrance of accessibility by the urban setting and the physical fence, the existence of many shading and seating elements, and most importantly the diversity of functions found on site. The place is very “humane” and civilized by the constant maintenance and the profound lighting elements and basic facilities. Instructive sign systems help users to stroll through the park in a comfortable way, with less to no obvious cameras. Monitoring personnel regulate the park through rules and enforcements. Finally the park’s animation dimension is diminished considerably as the park allows only certain category of people to enter through payment methods.

### **Case Study: Asr El-Shamee Garden**

The garden is located in a historical and lively urban setting of Coptic Cairo. After extensively examining the garden and the urban surroundings, it is been hypothesized that Asr Al-Shamee’ Garden excels in certain aspects of public spaces yet it lacks another characteristics. Its ownership of being publically owned and operated enhances its publicness. The garden is situated in a much known and culturally diverse urban setting near Coptic Cairo and Darb 1718 youth organization on the site’s macro-scale, thus improving the image and memory of the place. On the other hand, micro-scale design methods didn’t achieve full publicness levels due to the lack of seating, shading elements, basic facilities and functions. Civility characteristics achieved also a mediocre level of publicness yet there were no light provisions were found at the garden, highlighting a low level of animation at night. However, animation is enhanced due to the fact that the garden is open to all users allowing accessibility and diversity.

### **Case Study: Cairo Festival City Mall**

According to Dovey and the sociologist Sharon Zukin (1995), privately owned shopping centers have become the common public places of the American suburbia. The enclosed shopping center (ESC) originated in the U.S in the mid-1950s and it was exported to the rest of the developed world starting in the early 1960s. Cairo Festival City Mall is a contemporary form of the twenty first century public space. It became a heading for many individuals and families throughout Cairo. Although this research alienates the idea of

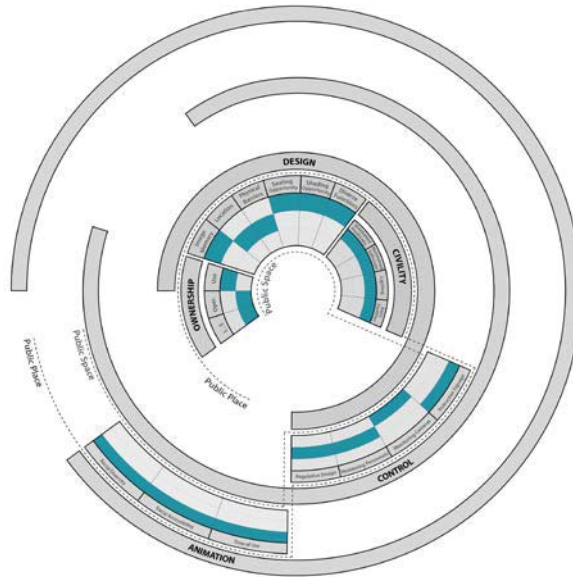


Figure 8. Model Index for Cairo Festival City Mall. Courtesy of Author.

categorizing public spaces according to they being successful or not, this section examines the mall's characteristics in comparison to the previous case studies. The ownership state differs drastically as it is legally operated by a private entity, Al Futtaim Group Real Estate Firm. Constant maintenance and management is achieved through the shops investment/revenues and to maintain the image of the mall. Concerning the control of public space, the results did show an increase in control measures especially electronic surveillance camera system, and monitoring personnel. Animation high levels are shown by the diversity of accessibility for multiple classes of users and their huge numbers, visiting the mall each year.

### Conclusion and Succeeding Prospective

It has to be acknowledged that there is no perfect public place. Each place has its own attributes and character and it is unique to the other. This research originates from asking the questions "what makes a public space?" and "how can one conceptualise and measure the term "publicness" of public spaces?"; as a result, one could not only able to assess publicness, but also compare attributes of public spaces to another. While exploring the public space literature available, five dimensions appeared as significant to elucidate the publicness of public space: ownership, design, animation, control and civility. After establishing the investigation tool, the three case studies were compared according to the five dimensions, illustrating a different "shades" of indicator levels. All the five meta-themes were seen as varying from a "more public" to a "less public" situation. By gathering the "more public" description of each meta-theme, the new model standard can be used as a benchmark to measure the publicness of created public places through the synergies of all the dimensions. The model addresses any identified limitations that a public space may have, considering "on" and "off" site conditions vehicular transportation to the place, vegetation, function uses, circulation patterns, and potential areas of security vulnerabilities, existing light conditions, and types and location of different utilities.

Another purpose of proposing this investigation tools is to help designers while designing a public space. From the three case studies that were tested, it has been indicated that certain shortcomings and problems of public spaces may result in a creative understanding and possible solutions to be implemented. Some draw backs of public spaces

may include: ownership private status, weak location and segregated urban setting, lack of seating and shading elements, lack of functions, lack of security and basic provisions, over-management, and neglected public spaces.

Finally, it is important to acknowledge the fact that the Model have laid a more substantial foundation not only for building more pragmatic studies in the field of public space research in the future, but also for analysing more and more forms of public spaces. Overall, this study can be seen as an experiment between social and physical sciences, aiming to express in a formula the “publicness” of public space. The tool triggers an interesting debate as it incites people to modify the model presented according to their subjective reasons and point of views. It is therefore recommended that the model is considered a prototype and that further research is needed in order to improve the current indicators or to find new ones in the notion that public spaces in Cairo may differ in certain ways than those in another countries. One way to do this is by putting the model to discussion in different professional forums, where experts in each of the five meta-themes can provide their expertise related to the current indicators or offer new insights.

## References

- Bachelard, G., Jolas, M., Danielewski, M. Z., & Kearney, R. (2014). *The Poetics of Space*. New York: Penguin Books.
- CABE (2007) Spaceshaper. A user's guide. London [Internet], Available from: ([www.webarchive.nationalarchives.gov.uk](http://www.webarchive.nationalarchives.gov.uk)).
- Carlson, L. C. (2002). *Context end Public Spaces: A Tale of Two Squares* . Simon Fraser University.
- Carmona, M. (2010). *Public Places, Urban Spaces: the Dimensions of Urban Design*. Milton Keynes UK: Lightning Source UK. Ltd.
- Dovey, K. (1999). *Framing Places: Mediating Power in Built Form*. London: Routledge.
- Gehl, J. (1996). *Life Between Buildings. Using Public Space*, Skive, Arkitekten Forlag.
- Gehl, J. and Gemzøe, L. (1999). *Public Spaces Public Life - Copenhagen 1996*. Copenhagen: The Danish Architectural Press and The Royal Danish Academy of Fine Arts School of Architecture Publishers.
- Gehl, J. and Gemzøe, L. (2000). *New City Spaces*. Copenhagen: The Danish Architectural Press.
- Glazer, N. and Lilla, M. eds. (1987). *The Public Face of Architecture: Civic Culture and Public Spaces*. New York: The Free Press.
- Hee, L. (2017). *Constructing Singapore Public Space*. Singapore: Springer Singapore.
- Kohn, M. (2010). *Brave New Neighborhoods: the Privatization of Public Space*. New York: Routledge.
- Lefebvre, H. (1991). *The Production of Space*. Oxford, Blackwells.
- Lofland, L.H. (1998). *The Public Realm: Exploring the City's Quintessential Social Territory*. New York, Aldine de Gruyter.
- Laila E. Elmasry (2013). *Landscape Architecture and The Planting Design of Al-Azhar Park*. Cairo: Lynch, K. (1960). *The Image of the City*. Cambridge: MIT Press.
- Madanipour, A. (2003). *Public and Private Spaces of the City*. London: Routledge.
- Mboup, G., & Warah, R. (2013). *Streets as Public Spaces and Drivers of Urban Prosperity*. Nairobi: United Nations Human Settlements Programme (UN-Habitat).
- Nemeth, J. and Schmidt, S. (2007). *Toward a methodology for measuring the security of publicly accessible spaces*. Journal of the American Planning Association, Vol. 73, No.3.
- Singerman, D. (2009). *Cairo Cosmopolitan: Politics, Culture, and Urban Space in the New Globalized Middle East*. Cairo: American University in Cairo Press.
- Sims, D., & Abu-Lughod, J. L. (2010). *Understanding Cairo: the logic of a city out of control*. Cairo: The American University in Cairo Press.
- Varna, G. (2014). *Measuring Public Space the Five Star Model*. University of Glasgow.
- Williamson, K. M. (2006). *Planning for Modern-day Public Forum Spaces New Urbanism and the Challenges of Hosting the American Public Realm*. Ann Arbor (Mich): UMI Dissertation Services.
- Whyte, W. H. (1980). *The Social Life of Small Urban Spaces*. Washington DC: Conservation Foundation.
- Easements, in LaFarge, A. ed. (2000) *The Essential William H. Whyte*. New York, Forham University Press.
- Zukin, S. (1995). *The Cultures of Cities*. Oxford: Blackwell Publishers.

# Role of Local Festivals in Promoting Social Interactions and Shaping Urban Spaces

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**Abstract:** Urban Spaces have played an important role in people's psychological life and in their integration with environment, as it is the mediator between people and their environment. Despite its importance, many communities suffer from the absence of positive communication between people and place. And this lead the governments to seek for a solution and they found that events can be used as a tool of enhancing the social engagement as they can reach a broad swathe of the population and have potential social benefits, like offering celebrations and building social networks within communities. In addition, they can help in build cohesive communities, offer employment opportunities and attract visitors to destination. More recently, there has been a focus on their ability to deliver social or political messages to audiences.

Festivals are considered the most effective patronize for social formats impact on the spatial formation, since the human is the main sponsor for forming the spaces that contain all the events that may be specific or temporary, thus it was essential to show physical and non-physical components for space formation in order to gain access to identify the reciprocal relationship between people and place and highlight the successful spatial expressions that help boost the spirit of communication between people and develop a sense of place.

The paper seeks for identifying the relation between people and urban spaces and how the dynamics of social life shaped the special spatial arrangements created. An analytical study was formed by observing the varieties of social behaviours occur within the urban spaces and analysing the reflection of these behaviours on the transformation of this space during local festivals. The results shows how the spatial setting and structure of the place can organize and control these relations and can contribute the feeling of belonging.

**Keywords:** Urban Spaces, Festival, Social Interactions, Human Behaviours, Enclosure, Centrality, Axiality, Permeability and Connectivity

## 1. Introduction

Nowadays urban festivals have become an attractive topic to most of the cities and their number has risen in recent decades (Gursoy et al,2004), as local authorities and stakeholders are convinced that through these events the image of the cities can be improved and make them more vibrant and cosmopolitan in order to generate economic benefits (Saayman and Saayman,2006).

Whereas several cities consider festivals as part of the urban regeneration thrust and place promotion activities, others are trying to raise their profile by organizing or hosting special events and annual festival (Herrero et al,2006).

In the past, the aim of festivals was to transgress boundaries of prevalent social and political order, but nowadays some cities harness festivals for more market-oriented purposes. Local authorities found that these events have become an economic key itself and make an essential contribution to the urban economy as they raise the value of properties and attract commercial development.

The role of the festival does not stand at that only, but they play a significant role in enhancing the local social life and shaping the social experiences in the local spaces, by creating new opportunities for social engagement and innervate this social bond. Furthermore, festivals in large cities heighten sensation, emotion, and memory by compressing many people and activities into a certain time and place (Fig.1).

We can consider festivals as part of everyday life that is characterized by the intensities of sensory experience (Guardian, 2004) which is formed by the social behaviours of the participants and their distinctive interactions with themselves and the physical settings of the places (Stevens, 2006).

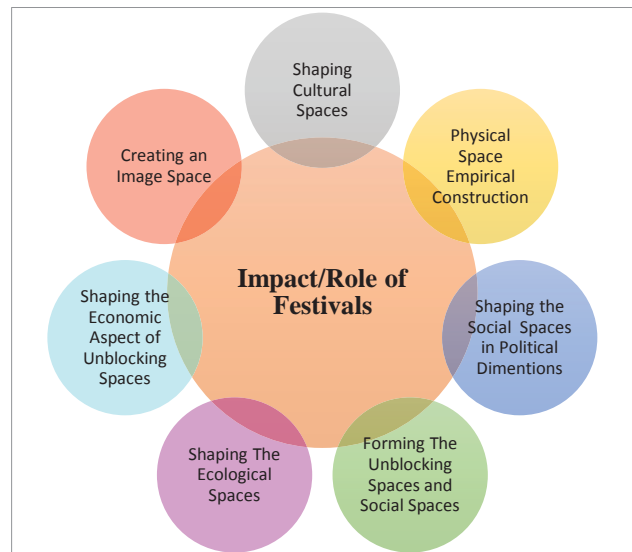


Fig. 1 - Shows the of festivals and their impact on communities

In this research paper, we will concentrate on the public spaces where festivals occupy and how the spatial behaviours of the participants affect the management of the place hosting them. By analysing the different social practices connected to the festival event, we can highlight the potential festivals can provide for improving and developing the everyday life and consequently maintain a good quality of life. The paper will focus on the diversity of actions through which urban spaces are appropriated and inscribed during festivals. The findings will illustrate how local social spaces can be redefined.

The research will cover two main themes that happened in Old Jeddah (Al-Balad) during the annual festival, and the study will show:

- a) The moral of the social needs and their effect on the spatial formation of place.
- b) The characteristics of space during the festivals.

## 2. Literature Review:

### 2.1 Urban festivals as a tool of enhancing cities profile

Urban festivals have become a popular organizational form for creating experience space and marketing cities. Through these events, the meaning of place and social life of users can be redefined and rediscovered and the identity of space will be promoted to a "distinctive city".

Festivals create the brand of a given destination by creating an impression of a memorable journey to the city, generating pleasant experiences and memories connected with it in order to persuade the recipient of the marketing message to choose this destination and not another (Cudny, 2016).

The experience economy framework has been applied to explore how certain places are arranged and organized (Hayes and Macleod, 2007-Avdikos, 2011), how users' experience and influences can be measured for developing marketing destination strategies (Morgan et al., 2009) for enhancing the attractiveness of place (Smith and Von Krogh Stand, 2011).

Festivals provide cities with a particular image especially when it is connected to a certain location or a place that has a specific theme. For this reason, several cities consider festivals as a method for solving image problems (Quinn, 2005)



## ***2.2 Urban festivals as a tool of creating social and cultural spaces:***

Festivals have a significant influence on the urban community. They can be considered as a component, which creates a broadly understood social capital, which is formed by interpersonal linkages, norms, and social relationships; as they built relationship between all the participants starting from the organizer till the inhabitants. Moreover, they are also in arena for expressing and consolidating opinions and values common to the urban community (Cudny and Rouba, 2011)

This is not the only role for festivals but Frey connected festivals to tourism and consider them as an attraction to visitors (Frey, 2000). Tourists enjoy the art, culture and entertainment offerings that make festivals become one of the fastest growing branches of industry. Tourists spend money to participate in such festivals and that affect the local economy and raises it. In addition, the city can be distinguished from other cities as a tourist destination (Baerenhddt and Haldrup, 2006). The economic impact of such urban festivals on the host society goes beyond the organized activity (Hiller, 1995). People who do not usually seek out cultural facilities can be introduced to venues they might otherwise have visited (Irina and Rianne, 2011).

Festivals do not attract only tourists but also talented performers, as it is a platform for supporting and promoting them. They can have a good opportunity to meet people who are interested in such particular art forms. Many festival organizers offer free concerts and exhibitions, which often take place in easily accessible public space such as street or square. In addition, organizers can mix between popular and talent performers in order to suit all tastes of music and art.

Altogether, these conditions can turn festivals into a meeting space for creative people and a place of popularizing high culture and developing cultural capital which consist of several elements like taste, familiarity with high culture, social and cultural convention , formal education and culture-related property which subsequently helps in renovating the existing cultural infrastructure and growing of other cultural development.

## ***2.3 Importance of festivals on places:***

Festivals have become a modality for expressing the close relationship between identity and place (Quinn, 2005), throughout time, the festival and the host place can become inextricably linked (Getz, 2008). Furthermore, by time, successful festivals can become centered to the host city's identity (Gibson and Davidson, 2004), so the location of the festival may have an impact on its content, objectives, and successes. Festivals that are linked to particular places (Place-bound festivals) are usually organized to honor certain historical events or show traditions related to the local culture of the host place and demonstrate what a society believes to be its essence.

These festivals often offer physical and moral experiences that connect people to place (Derret, 2003), as they involve collective celebrations with diverse purposes like building social cohesion by bonding ties within the community, learning and celebrating cultural traditions that belong to the place and drawing on shared histories and local practices. This means communicating an attractive atmosphere which comes from place-bound activities, events, attractive places and diverse social spaces can make visitors and inhabitant feel inspired and connected to the place (Lorentzen, 2009).

## 2.4 Transformation of Urban Space

During festivals, cities are reshaped and transformed both by altering their spatial constitutions or by granting them a special and specific identity. In addition, streets are closed off, unwanted elements are removed, buildings are refurbished, alternative spaces are created and extra-ordinary performances are staged in places usually reserved for more temporal activities. All of these things occur in order to encourage visitors to participate and feel safe inside the space.

So festivals provide spaces to redefine cities and make them live in temporal rhythms of activities and people who look to the urban practices that uphold the city rather than seeing it as unitary phenomena. These cities become an experiencescape and ordinary spaces are transformed to festival spaces with alternative activities that contrast the routine of everyday life (Jamieson, 2004).

## 2.5 Festivals and Social Behaviours

Festivals generate regulated and liminal spaces through temporary appropriations of local settings as they involve physical modifications of local spaces, which promote some social arrangement. Willem Braun emphasizes that such events set up unceremonious, intersubjective spaces where a multiplicity of identities can be expressed and deliberated (William, 1994); while Ravenscroft and Gilchrist suggest that this physical and temporal bounding facilitates the disciplining of social behaviour during festivals. These social behaviours usually have the potential to differentiate and particularize social identity.

According to some studies regarding the satisfaction of visitors during festivals, it was found that it depends on the ability of attendees to adapt with the festival atmosphere as a socially integrative, interactive and emotionally engaging experience. Moreover, this can be achieved and facilitated for gaining experience under certain conditions that urban designers and organizers should take it into consideration like:

- Permeability, which means the ability of visitors to move freely and comfortably along a diversity of paths between different spaces and creates personal itineraries.
- Centrality as the event should be spatially connected.
- The availability of un-programmed public spaces and semi-public (third places) adjacent to Formal venues and circulation routes, so informed socialization could be formed as it attracts visitors and generates economic benefits (Morgan, 2007)

Steven's also confirms in his broader study of informal activities in public spaces that three-dimensional elements of public spaces identified by Lynch (1960) nodes, paths, and boundaries are directly involved by users as they perceive act out the potential behavioural affordances of urban public spaces.

Festivals can be a tool that cities can use to enhance a place or enrich it as the four main elements that make a successful place can be found in a well-organized event or festival (Fig.2).



Fig. 2 - Shows Place Making Elements

Source: <https://www.pps.org/>

### 3. Methodology

The fieldwork for this research paper had two stages: The first was observing the varieties of social behaviours occurring within the urban spaces during local festivals and the sensory and spatial perceptions available in that context; the second was to analyse the reflection of these behaviours on the transformation of this space. The observation stage focus on showing the social characteristics and behaviours of users and the interactions among them and how the spatial setting and structure of the place hosting the event can have an influence on organizing and controlling these relations. Together these aspects illustrate the role that organized festival events can play in informal socialization and in contributing the feeling of belonging to a place.

The paper studies one of the poplar events that is held annually in a significant place in Jeddah city, lasting 10 days. This event is known as “Historic Jeddah Festival” and it is the first of its kind in Jeddah City that recalls the past of both the place and the people, in a period of time through which Jeddah city had passed over more than half a century ago. The festival was initiated in 2014 and is free. It aims to promote the Kingdom as the House of culture, literature and Arabian and Islamic history, while preserving the heritage and the cultural treasures. It links the glorious past of the Kingdom with its prosperous present, allowing the Jeddahs’ visitors to know about it, and introduces new generations to the heritage, culture, traditions and history of the residents of the Historic Jeddah area.

The Festival is held daily from 30<sup>th</sup> March to 8<sup>th</sup> April, and it features various events each year, including dozens of programs and activities that starts daily from 5 pm. to 11 pm. , in addition to forums and independent performing arts that spread along the historical place (Al Balad). Furthermore, it has a specific annual theme that shows the traditions and links between behaviours and attitudes of people in the past and present.

The Saudi Commission for Tourism and National Heritage (SCTH) chooses the historical area of Jeddah (Al-Balad) to be the place of the festival as it has very particular geographical, cultural, political and financial contexts. It includes a number of monuments and heritage buildings of archaeological interest, such as the Old Jeddah wall and its historical open squairs (e.g. Al Mazloom, Al Sham, Al Yemen, and Al Bahr Haras), and a number of historic mosques (e.g. Uthman ibn Affan mosque, Al Shafi’i mosque, Al Pasha mosque, Akash mosque, Al Memar mosque and Al Hanafi mosque), in addition to these several historical markets (Souks) found there.

The study focus on how attendees act within the spaces specially arranged for this festival in order to allow urban designers to sketch out a range of ways in which the spatial arrangements of urban spaces during festivals give shape to informal socialization and the production of meanings, and city brand.

The researcher visited the site of the festival before (October 2016) and during the festival event (April 2017) and observed the diversity of formal and informal activities, which were shaped around the event and how the attendees’ reactions to fulfil their needs affected the arrangement of the open spaces and paths inside the site. The field visit depended on site analysis, field notes, live observations of human behaviour in public settings and photos, in addition to the archival research of media reports and festival programs from previous years.

The observations concentrated on two main aspects that shaped the space, which are:

- a. Social and Humanity Aspects (Behavioral Aspects) including diversity of user patterns, activities occurring, interactions between attendees and participants “Organizers, Sponsors, Sellers, Talented Performers” and involvement of local businesses, institutions and social groups in the festival events

- b. Spatial Aspects (Urban Space Settings) including reorganization and transformation of public and private space for the festival, intensive uses of spaces that are usually unoccupied and adding some elements to enrich the open space.

Through the precise field visits to the place before and during the festival and analysing, the spatial settings that occur with respect to the attendees' behaviours, the research figures out the significant role of the four physical and spatial characteristics of the urban (enclosure, centrality, axuality and permeability) on the organization of actions and behaviours of occupants.

#### **4. Analysis and Findings:**

Before we start the analysis of the impact of the social aspects on urban spaces during the Historic Jeddah Festival, it is necessary to concentrate on some social features for the users, which should be taken in consideration due to its importance on succeeding the event. The research divide these features into two main features, which are:

a) Congestion:

During Historic Jeddah festival, urban spaces are crowded with different users more than any time else. In addition, its level of overcrowding varies through the day, as it is more crowded at night than in day-light due to the nature of the climate (Hot and Dry Climate) - (Fig.3a-b); moreover, most of the attendees work. The congestion is caused when there is a conflict between activities that are performed at the same time in the same place. (Carmona et al., 2010).

Although there is a negative side to congestion, in some cases people prefer it for social interactions, which results in a collective behaviour.

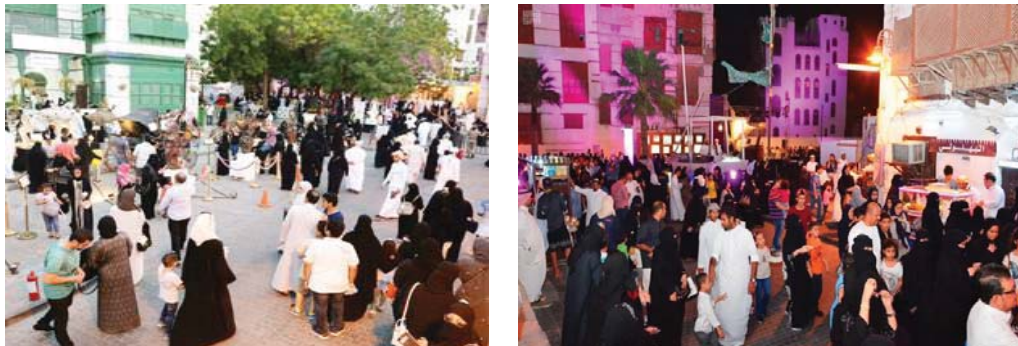


Fig. 3 (a-b) – Shows how the space is crowded in night more than in day light

b) The Diversity of Users :

Historic Jeddah festival is characterized by a diversity of users in terms of age, gender, social and cultural level. Users can be divided into two main types: Residents of the District or Owners/Labours who work in shops, and visitors who only come to festivals to participate if they find attracting elements there. Those visitors might be Jeddah citizens who feel that this festival belongs to their culture and traditions and want to share it with their kids or foreigners who are excited to transfer knowledge and traditions with other people and enjoy the feeling of place (Sense of Place) especially that old Jeddah has its identity.

Based on the above, we can consider that the social features is one of the main factors that reshape the urban space and help in the development of physical and behaviour of space and users.

The following analysis shows that although the site of Historic Jeddah Festival is appropriate for such events and can offer opportunities for social interaction, self-expression



and self-realization to develop unless we ignore any of the four key spatial characteristics enclosure, centrality, axiality and permeability and connectivity.

### 1) Enclosure

One of the benefits of the site of Historic Jeddah Festival is that the place is totally surrounded by large walls. During normal days, vehicles can move inside and there is no separation between pedestrians' paths and vehicles' roads but when the festival starts, only people can enter through the huge old gates whereas vehicles are prohibited from going inside (Fig.4). This helps in expanding the spaces where users can move safely as well as include extra temporary booths to give more participants the chance to share their stuff and open markets for non-professional projects (Fig.5). Furthermore, it helps reduce air pollution, traffic noise and increases the ability for users to enjoy watching the displayed elements, deal with the merchants without feeling scared of cars. In addition, the density of people and their opportunities for social interactions increase.



Fig.4 – Shows the Huge Gates of the festivals that are open for people only



Fig.5 – Shows how people can move safely and free during the festival

The enclosure of the urban space helps in controlling the movement of people inside and keeps it smooth and easy. In addition, people will know the initial start of the festival and it will lead them to a one-way circulation and ensure they will pass through all the activities held there.

### 2) Centrality

Centrality describes the action of a central element in its periphery. It was defined as a hierarchical concept between service and attraction. It may cause congestion if it is not well arranged or the distribution of activities is not appropriate. The attractiveness and circulation of this element is based on the efficacy of the central pole and its accessibility.

In normal days, the central poles (Nodes) in the site are always empty as there are no themes or activities there and there is no use for the central pole (nodes) (Fig.6).



Festival Area 
 
★
 Famous Buildings  
 Nodes (Gathering and Activities)





Fig.6 – Shows that some of the nodes are empty and without any theme or activities in normal days

While during the Festival (Historic Jeddah Festival), most of the nodes have a certain use and they are in order to reduce congestion. These Nodes are divided to three main types, each as its own characteristic:

- Nodes near the gates are used as gathering points; people can gather there to start their journey through Old Jeddah and participate in the activities of the festival. These nodes are usually very crowded thus there is no furniture in it (Fig.7).
- Separate Nodes are spaced out along the paths providing particular points of crowd concentration. These nodes are for the activities (Fig.8) and the talent performances especially art and talent shows; as they acts as small exhibitions where talent people can show their work (Fig.9), people usually stay inside it and it is not with furniture.
- Large Nodes at the end are used as a meeting space where people can sit, have conversations, and enhance the social interactions between them. These nodes are full of furniture, food booths and temporary tents that increase the opportunity for the interactions between different social ties (Fig.10).



Fig.7 – Shows the gathering node



Fig.8 – Shows how the nodes can be used for activities

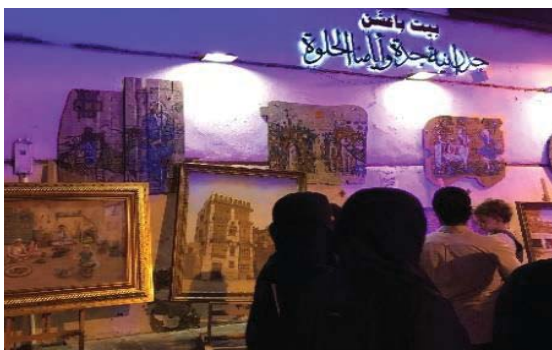


Fig.9 – Shows art exhibition for talented people



Fig.10 – Shows using end nodes as a social

Sometimes organizers add huge temporary structure elements (Inflated Building) for shows that talk about history, local life and traditions. The organized events of the festival go hand-in-hand with physical planning to develop the public realm as a socio-cultural medium for interaction.

### **3) Axiality:**

Historic Jeddah Festival is formed in order to show different things about the history and traditions of this place, as it is the core of Jeddah. Many events happened there and some famous people used it, therefore stakeholders and organizers consider it an open exhibition where people should pass through all its parts. In order to facilitate the movement and avoid informal ones, signs are used and sometimes barriers are placed to separate the two directions. On the other hand, people can move freely in all paths during normal days.



Fig.11 a-b – Shows how famous places are decorated and the lighting of paths



Fig.12 – Shows people actions that causes slowing in the movement among the paths



There is another benefit from the one-way circulation for the shops' owners, as they will be assured that everyone will pass by their shops. In addition to that, organizers use the wall of the famous buildings there as a form digital art with different shapes as well as light above the paths to make them liveable and people do not feel bored (Fig.11 a-b). Most of the secondary activities' rely upon the linear structure established for the organized event.

One of the problems found was that even though the movement of people was easily organized, but the congestion lead to slower movement as some activities attract people and some booths were placed among the paths causing people to stop suddenly without considering that they should move especially that some paths are narrow (Fig.12).

### **4) Permeability and Connectivity:**

The idea of permeability and connectivity is connect and integrate the site with the surrounding community and areas through a network of diverse public spaces including paths and open spaces. Connections with existing streets will invite pedestrians into and through the site. Permeability can enhance the attractiveness of a neighbourhood through the provision of additional useable open space; it can increase social interactions by facilitating more activity in the public realm, and maximize the potential to walk to a range of services.

Old Jeddah (Al Balad) has good linkages between all its areas through the pedestrian paths. During the festival not all the paths are opened. Organizers only use part of the neighbourhood for the festival, therefore at times people are unable to recognize parts in the site that they did not visit, unless local citizens show them. On the other hand, we can consider the end of the festival as a cul de sac where the opportunities for social interaction increase (Fig.13). The site also includes many stalls selling ethnic food, crafts and traditional clothing that attract people especially those who are unaware of old Saudi traditions and

customs (Fig.14). The festival encourages more intensive and varied uses of places that already carry memories and meanings for local citizens, and opens up community spaces so that new meanings can be brought to them. Also it provides better spatial opportunities for local citizens to act out and develop their own identities, and to communicate with other people from different cultures.



Fig.13 – Shows Cul de Sac as a social



Fig.14 – Shows the place's identity while moving in paths

Finally we could consider Historic Jeddah Festival as a tool for enhancing social engagement and the discovery of place, making strong connections to local identity and everyday life, and it illustrates tensions between efforts to control place and image, and local citizens' propensity to continuously create, circulate and debate images and ideas about places and identity.

Furthermore, such a festival provides an opportunity to develop identity awareness for local children who participate in it, and develop their skills and confidence in bodily performance as a means through which they can communicate identity and meanings to others.

## 5. Conclusion:

This paper has examined the role of festivals on enhancing the social interactions between people and how urban space can be shaped in order to facilitate this engagement with the diversity of human needs and demands. Findings of the paper shows that festivals are often staged for broad social goals, including engaging the community, breaking down entry barriers, and increasing tolerance and acceptance of diversity, beside its influence on promoting a 'distinctive city', which is considered an important feature of the experience economy.

Throughout the study, It has shown that urban spaces become dynamic during festival time, and neighborhood spaces are constantly being produced and reproduced with respect to their identity, meaning, rules, and social uses. Urban open spaces supports collective life as they reflect the inhabitant's culture, develops their everyday activities, and creates the image of a place, where architectural structures and sociocultural features are mobilized, framed and represented.

According to the previous part, urban designers should not focus only on the physical urban settings without taking in considerations users of the space. They should create a place for various leisure and outdoor activities. They should enhance the urban spatial spaces by increasing their ability to create connections and networks and provide attendees with a celebratory experience. In order to achieve that, they should take in consideration the effect of the four key spatial characteristics as each of them had a role in facilitating social interaction. The idea of enclosure for the space makes it safer and provides an identity, while



the centrality shows the ability the space has in attracting people through the arrangement and distributions as it can carry different uses that fits all users.

In addition, the other two parameters axiality and permeability and connectivity do not only help in controlling the movement but they could offer a good opportunity for introducing new uses into local space and help in showing the most significant buildings in the space that may give the space identity and affect the feeling of people towards the space. The axial paths and movement during the festival emphasizes that the flow of people are free and Communication and interaction occur between those on the move and others who are stationary.

Moreover, Festival organizers felt that their festivals occupied unique place in society, given their ability to create connections and networks and provide attendees with a celebratory experience, but they have to take in consideration that the space for the festival should not be too tightly regulated. In spite of the obvious benefits of enclosure and centralization, there are good reasons to loosen up the physical and managerial frame within which festival occur, so we can consider the four characteristics as important aspects that help in understanding the spatiality of organized festivals. More importantly, they illustrate how the same framework gives insight into unplanned and unexpected local activities.

By analysing people's reactions during the festival, we could find that they act out the possibilities inherent in the festival spaces and their participations add meaning and value to the space of the festival through the un-programmed activities, and not only by decorating or renaming them. Festival can also reawaken old meanings in spaces, whether festival organizers want it or not.

In order to promote social interaction, urban designers should work in collaboration with others and in multi-disciplinary teams, understand the diverse needs, behavioural norms, physical abilities, and social and spatial patterns that characterize the community. They should design sites, facilities, and systems to provide independent and integrated use by individuals with physical and cognitive disabilities. The role of urban designers is not only design but they should elicit, understand, and reconcile the needs of the user groups, and the public and community domains.

Furthermore, the role of festival organizers needs to be unpacked further. They should know what forms of embodied engagement they offer meet local needs, and the ways in which festivals and their spaces are active, tactile, and malleable.

## References

- Andersson, I. (2014) Placing place branding: an analysis of an emerging research field in human geography. *Geografisk Tidsskrift-Danish J Geogr* 114(2):143–155
- Avdikos, V. (2011) Local hegemonic blocs: The case of tourism in Rhodes. *European Urban and Regional Studies*, 18(1): 77–92.
- Bærenholdt, J. and Haldrup, M. (2006) Mobile networks and place making in cultural tourism: Staging Viking ships and rock music in Roskilde. *European Urban and Regional Studies* 13: 209–224.
- Cudny, W. (2014) Festivals as a subject for geographical research. *Geografisk Tidsskrift-Danish J Geogr* 114(2):132–142
- Cudny, W. and Rouba, R. (2011) Theatre and multicultural festivals in Lodz as a free time management factor among the inhabitants and tourists in the post-industrial city. *Acta Geographica Universitatis Comenianae* 55(1):3–22
- Derrett, R. (2003) Making sense of how festivals demonstrate a community's sense of place. *Event Management* 8: 49–58.
- Dinnie, K. (2011) *City branding: theory and cases*. Basingstoke, Hampshire, Houndmills [England]; Palgrave Macmillan, New York

- Frey, B. (2000) The rise and fall of festivals: Reflections on the Salzburg Festival. Working Paper No. 48. Institute for Empirical Research in Economics, Zurich.
- Gardiner, M. (2004) Wild publics and grotesque symposiums: Habermas and Bakhtin on dialogue, everyday life and the public sphere, *Sociological Review*, 52, pp. 28–48.
- Getz, D. (2008) Event tourism: Definition, evolution, and research. *Tourism Management* 29: 403–428.
- Gibson, C. and Davidson, D. (2004) Tamworth, Australia's 'country music capital': Place marketing, rurality, and resident reactions. *Journal of Rural Studies* 20: 387–404.
- Gursoy D, Kim K and Uysal M (2004) Perceived impacts of festivals and special events by organizers: An extension and validation. *Tourism Management* 25: 171–181.
- Hayes, D. and Macleod, N. (2007) Packaging places: Designing heritage trails using an experience economy perspective to maximize visitor engagement. *Journal of Vacation Marketing*, 13(1): 47–58.
- Herrero L, Sanz J, Devesa M, Bedate A and del Barrio M (2006) The economic impact of cultural events: A case-study of Salamanca 2002, European capital of culture. *European Urban and Regional Studies* 13: 41–57.
- Herrero, LC., Sanz, A., Devesa, M., Bedate, A. and Del Barrio, MJ. (2007) Economic impact and social performance of cultural macrofestivals. In: Richards G (ed.) *Cultural Tourism. Global and Local Perspectives*. Binghamton, NY: Haworth Hospitality Press, 303–328.
- Hiller H (1995) Conventions as mega-events: A new model for convention–host city relationships. *Tourism Management* 16: 375–379.
- Jamieson, K. (2004) Edinburgh: The festival gaze and its boundaries, *Space and Culture*, 7(1), pp. 64–75.
- Johansson, M. and Kociatkiewicz, J. (2011), City festivals: creativity and control in staged urban experiences, *European Urban and Regional Studies*, 18(4) 392–405
- Lorentzen A (2009) Cities in the experience economy. *European Planning Studies* 17: 829–845.
- Lorentzen, A. (2009) Cities in the experience economy. *European Planning Studies*, 17(6): 829–845.
- Mikkonen, J. and Pasanen, K. (2010) Economic and socio—cultural impacts of two cultural festivals of Savonlinna. In: Paper for global events congress IV: events and festival research: state of the art, Leeds. [http://www.eventsandfestivalsresearch.com/files/proceedings/Mikkonen\\_Pasanen\\_FINAL.pdf](http://www.eventsandfestivalsresearch.com/files/proceedings/Mikkonen_Pasanen_FINAL.pdf).
- Morgan, M. (2007) Festival spaces and the visitor experience, in: M. Casado-Diaz, S. Everett and J. Wilson (Eds) *Social and Cultural Change: Making Space(s) for Leisure and Tourism*, pp. 113–130 (Eastbourne, UK: Leisure Studies Association).
- Morgan, M., Elbe, J. and De Esteban Curiel, J. (2009) Has the experience economy arrived? The views of destination managers in three visitor-dependent areas. *International Journal of Tourism Research*, 11(2): 201–216.
- Ooi CS (2010) Branding cities, changing societies. *Creative Encounters Working Paper* 45:3–17
- Ooi CS, Pedersen S (2010) City branding and film festivals: Re-evaluating stakeholders' relations. *Place Branding Public Diplomacy*. 6(4): 316–332
- Ooi, CS (2002a) Cultural tourism and tourism cultures: the business of mediating experiences in Copenhagen and Singapore. Copenhagen Business School Press, Copenhagen
- Quinn B (2005) Arts festivals and the city. *Urban Studies* 42: 927–943.
- Ravenscroft, N. & Gilchrist, P (2009) Spaces of transgression: Governance, discipline and reworking the carnivalesque, *Leisure Studies*, 28(1), pp. 35–49.
- Saayman, M. and Saayman, A. (2006) Does the location of arts festivals matter for the economic impact ? *Papers in Regional Science* 85: 569–584.
- Smith, A. and Von Krogh Strand, I. (2011) Oslo's new Opera House: Cultural flagship, regeneration tool or destination icon? *European Urban and Regional Studies*, 18(1): 93–110.
- Stevens, Q. & Shin, H. (2014) *Urban Festivals and Local Social Space, Planning, Practice & Research*, 2014, 29(1), pp. 1–20,
- Stevens, Q. (2006) The shape of urban experience: A reevaluation of Lynch's five elements, *Environment and Planning B: Planning and Design*, 33, pp. 803–823.
- Van Aalst, I and Van Melik, R. (2011), City festivals and urban development: does place matter?, *European Urban and Regional Studies*, 19(2) 195–206
- Willems-Braun, B. (1994) Situating cultural politics: Fringe festivals and the production of spaces of intersubjectivity, *Environment and Planning D: Society and Space*, 12, pp. 75–104.
- Yeoman, I., Robertson, M., Ali-Knight, J., Drummond, S. and McMahon-Beattie, U. (eds) (2004) *Festival and Events Management. An International Arts and Culture Perspective*. Oxford: Elsevier Butterworth-Heinemann.



# Social Sustainability and Urban Form In The Cities Of Developing Countries: The Case Study Of Mersin.

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**Abstract:** There have been limited researches about the social aspects of sustainability in the context of cities of developing countries. The cities in the developing countries are growing rapidly due to their high economic growth rate but on the other hand this brings serious problems to the city (Like insufficient infrastructure, urban poverty and housing) (UN HABITAT, 2006; UN ESCAP, 2005). The main aim of this paper is to evaluate the relationship between social sustainability and urban form in the context of cities of developing countries. Selected aspects of social sustainability were examined in the context of Mersin. Mersin is the one of the harbour cities of Turkey which has SYRIA immigrants. We collected data from the 3 case study neighbourhoods of different densities (higher, medium, and lower) and built forms within the Mersin Metropolitan region to evaluate relationship between social sustainability and urban densities. Findings showed that there is a significant relationship between residential density and the associated types of housing and social sustainability.

**Keywords:** Social Sustainability, developing countries, urban form.

## Introduction

As a concept of sustainable development, there are many debates about social aspect of sustainability in terms of urban form in the context of cities of developed countries. It is widely known and discussed in the literature that cities in developing countries which have more compact, high-density and mixed-use urban forms are environmentally sound, efficient for transport, socially beneficial and economically liveable (Dempsey et.al., 2011; Bramley et.al., 2009a; Bramley et.al., 2009b). In the case of urban areas of developed countries, maybe it can be a solution but on the other hand, there have been a very little research about the social aspects of sustainability in relation to urban densities and form in the context of developing countries.

In many cities of developing countries, their high economic growth rate, makes the gap between rich and poor widening (Bond, 2006). So that achieving social sustainability is important with economic and environmental sustainability in the context of developing countries.

The literature and academic works, has been suggested a high density compact form of development as a solution of urban problems for the cities of developing/developed countries (Dave, 2008; Bramley et.al., 2009a; Bramley et. Al., 2009b)

Sustainable development is a widely used term but its social dimension on urban policy, housing and planning in Turkey is always been neglected. In Turkey, especially in İstanbul and then in other big cities, high-rise residence production accelerated due to population growth, land insufficiency, changing consumption habits, technological

improvements and economic concerns. This new form of housing production and built form has affected not only land-house prices and many social aspects and quality of life. Effects of such policies, changes the traditional lifestyles, residential culture, neighbourhood relations and created a spatial differentiation of their inhabitants in many cities such as Mersin. This research is evaluating the effect of densities in the context of urban form on the social aspects of sustainability to inform the future policies related to growth and development control. We take the Mersin Metropolitan Region as a case study.

### The Concept of Social Sustainability and Urban Form

Definition of sustainability is wider in the sustainable development literature. Sustainable development literature emphasises the importance of 'social' aspects of sustainability. Polese and Stren (2000; 15-16) defines social sustainability as; 'development (and/or growth) that is compatible with harmonious evolution of civil society, fostering an environment conducive to the compatible cohabitation of culturally and socially diverse groups while at the same time encouraging social integration, with improvements in the quality of life for all segments of the population'

Urban and planning policy has not been aware of the significance of the social sustainability in the urban development.

Based on academic and policy literature Bramley and Power, 2009; Bramley et. Al., 2006; Dempsey et.al., 2009) defined 'social sustainability' with two main dimensions;

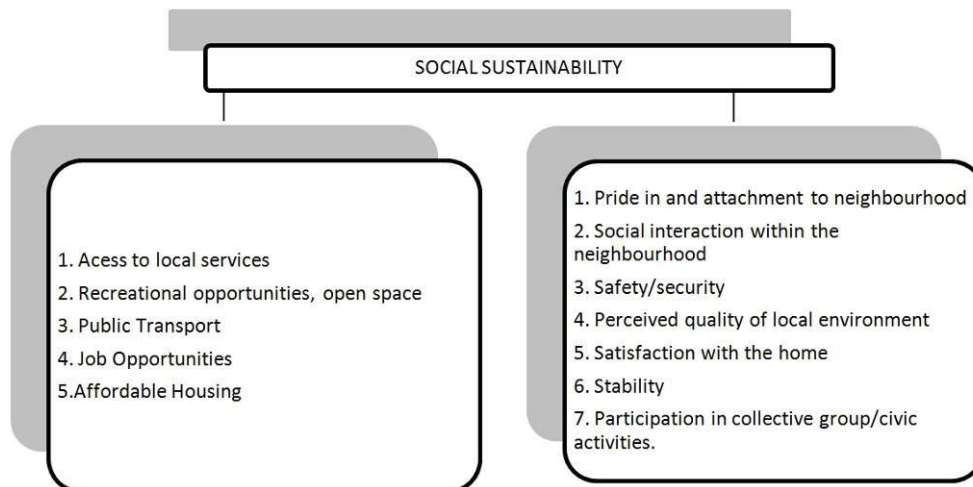


Figure 1. Main Dimensions of social sustainability (Bramley and Power, 2009).

Social equity includes access to local services, recreational opportunities, public transport, job opportunities and affordable housing, while sustainability of community includes various dimensions such as attachment to neighbourhood, social interaction, safety/security, and perceived quality of local environment, satisfaction with the home, stability and participation in collective group/civic activities (Fig.1). According to Bramley et.al., 2009, these two main dimensions of social sustainability is same or overlap with other terms, for example 'social exclusion/inclusion, social capital, social cohesion. All these terms together affect the quality of life which has been labelled as 'sustainability of community' (Bramley et. Al., 2009). They discussed social aspects of sustainability widely in the literature in the context of cities of developed countries (Burton and Mitchell, 2006; Dempsey, 2006). The aim of this research was to establish the similarities and differentiates in the relationship between urban form and social sustainability in developing countries of cities.

For this reason, we selected the social aspects of sustainability, which have been widely discussed in the academic works and literature in the context of developed countries;

1. Access to local services
2. Recreational opportunities, open space
3. Pride in and attachment to neighbourhood
4. Social interaction within the neighbourhood
5. Safety/Security
6. Satisfaction with the home/neighbourhood

In the literature, it has been claimed that higher densities can make access to social services and facilities, easier than lower densities in developed countries (Bunker, 1985; Burton, 2000; Haughton and Hunter, 1994). 'You need to have density to have facilities' (Burdett et. Al., 2004). But these researches are all for developed countries.

To measure social equity, accessibility has been acknowledged as a fundamental measure (Barton, 2000a; Burton, 2000b; Dempsey et. Al., 2011). In this research we measured access to local services with the distance from the centre of the neighbourhood to each daily-use facility like; shops, school, health, open space and park, bank and so on.

It has been argued, there were relationship between physical settings, activities and meanings (Gehl, 2001; Lynch, 1960) Relph states the sense of place that 'to be inside a place is to belong to it and to identify with it' (1976:49). Pride/sense of attachment to a place is considered as a dimension of social sustainability, because of its definition as a component of people's enjoyment of their neighbourhood which they lived in (Nash and Christie, 2003). It has been acknowledged that residents' sense of place attachment relates to the physical environment (Dempsey, 2011).

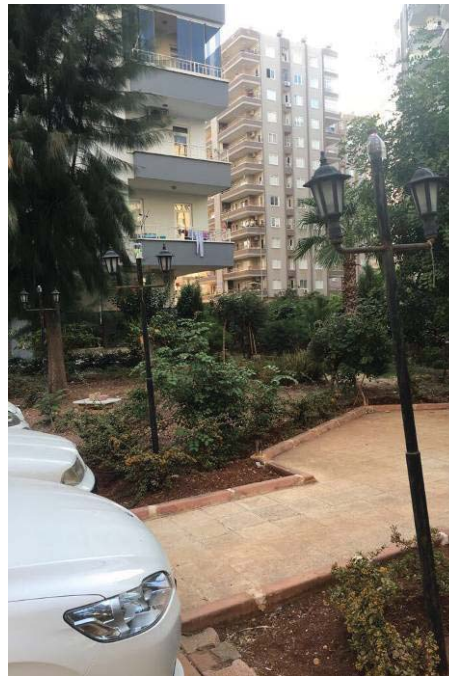
Another fundamental part of social sustainability is safety/security of a neighbourhood which is perceived by their inhabitants (Barton, 2000a). There is relationship between the other dimensions of community sustainability and the feelings of safety in a neighbourhood (Dempsey et.al.2011). If there are no crimes in a neighbourhood, the inhabitants can feel secure and safe in their social interactions with other people and participation in community activities. Some physical factors can affect the safety/security of the neighbourhood, too. For example, Worpole, 2003 mentioned that poor condition and maintenance of the built environment can have negative psychological effects on people's sense of safety.

### **Methodology**

Mersin was particular an interest of this research because it takes one of the most cities of immigrants from the SYRIA. It is one of the harbour cities of Turkey. Mersin faces many of urban challenges of other cities in developing countries. We collected data from the 3 case study neighbourhoods of different densities (higher, medium, lower) and built forms within the Mersin Metropolitan region to evaluate relationship between social sustainability and urban densities.



Lower



Medium



Higher

Fig. 1. Neighbourhoods of Different Densities

### ***Findings and Discussions***

Among the respondents 44,80% are belong to lower density, 39% higher density and 15,20% are living in medium density areas. (Fig. 1.) 61,5% are female and 38,10 % are male. 65,7 of the respondents are house holders. 34,30 % has no child while 27,6 of the respondents has two children. (Fig.2).

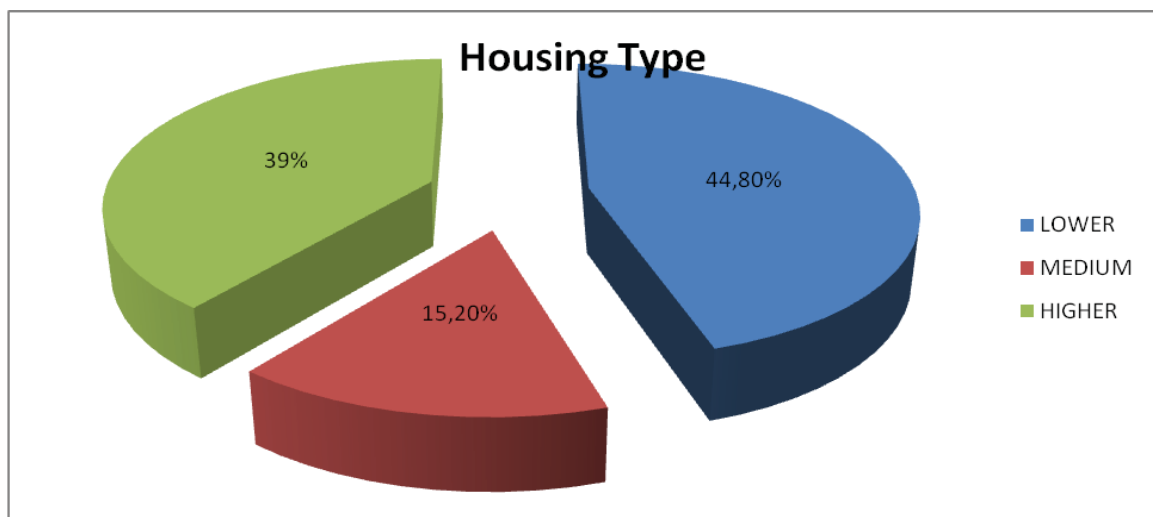


Figure 2. Housing Type

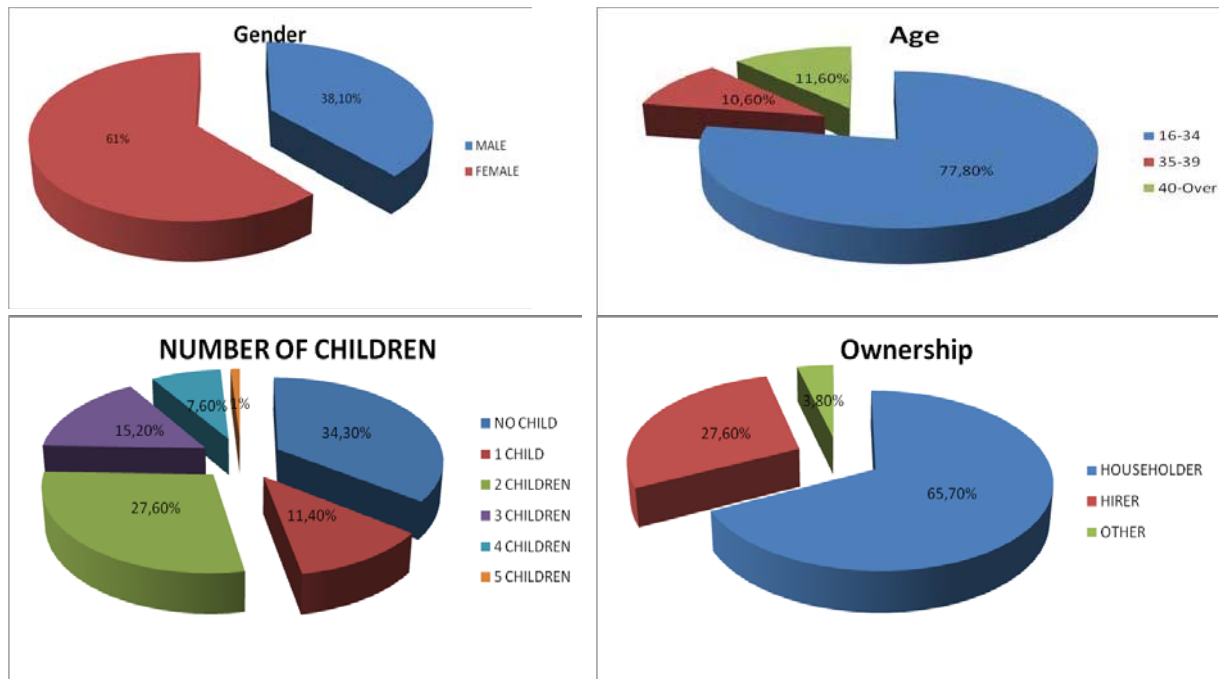


Figure 3. Respondents' Profile

Social equity encompasses 'access to services, facilities and opportunities. Accessibility refers to the equality of access to services and opportunities and recreational opportunities and open space. %68,6 of the respondents found their settings close to downtown and %57,10 founds close to local services. (Fig.4)

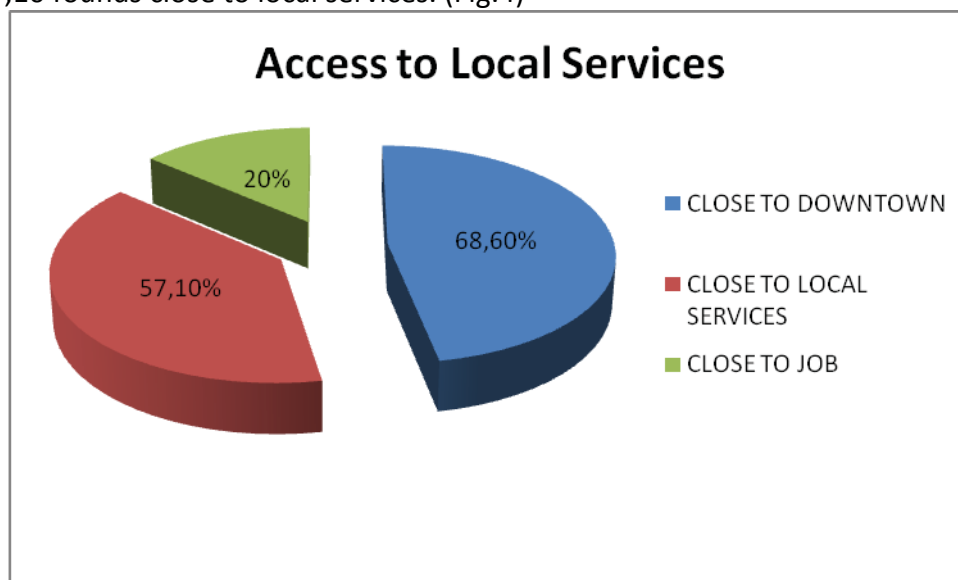


Figure 4. Access to Local Services



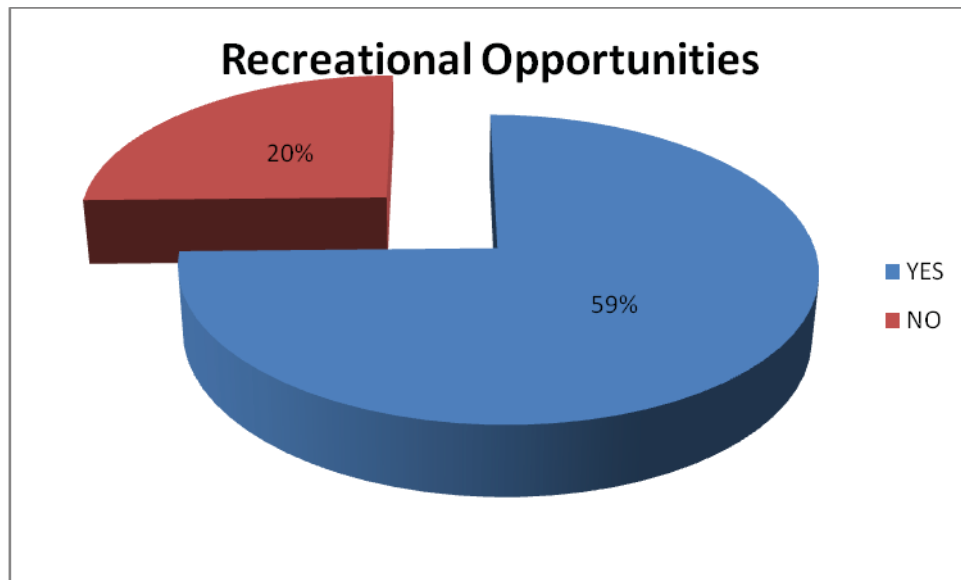


Fig. 5. Recreational Opportunities

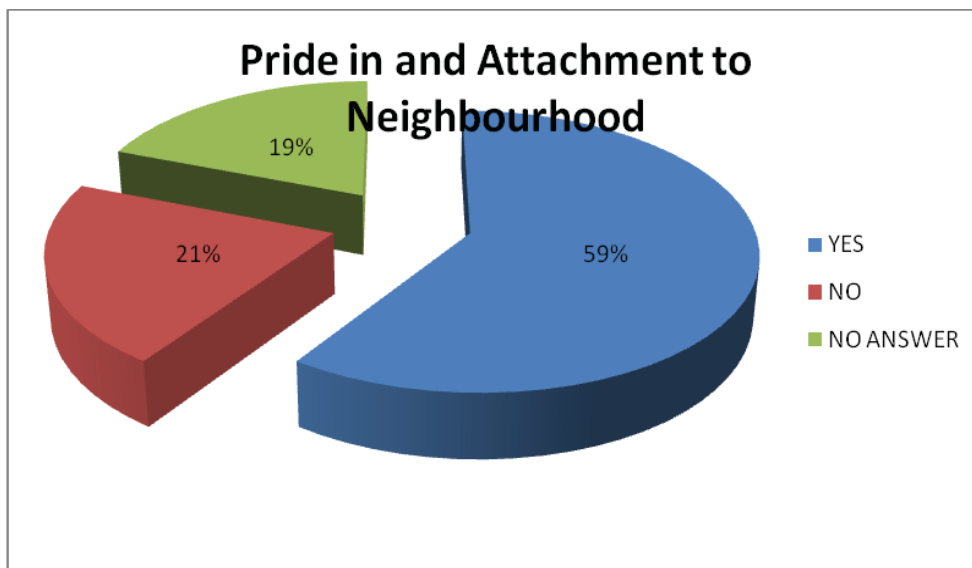


Fig. 6. Pride in and Attachment to Neighbourhood

Due to different needs and satisfaction from a living environment such as street design, shops, institutions, parks, pedestrian ways, safety and accessibility in residential areas., smaller groups need to be developed which all together define the neighbourhoods. People living in a society in an area also make up the members of that society. Every member of a group of people who lives in a dwelling is inherently a member of that society as well. %59 of the participants feels satisfactory about their environment and their setting. %59 of the participants has recreational facilities and opportunities. (Fig.5) and (Fig.6)

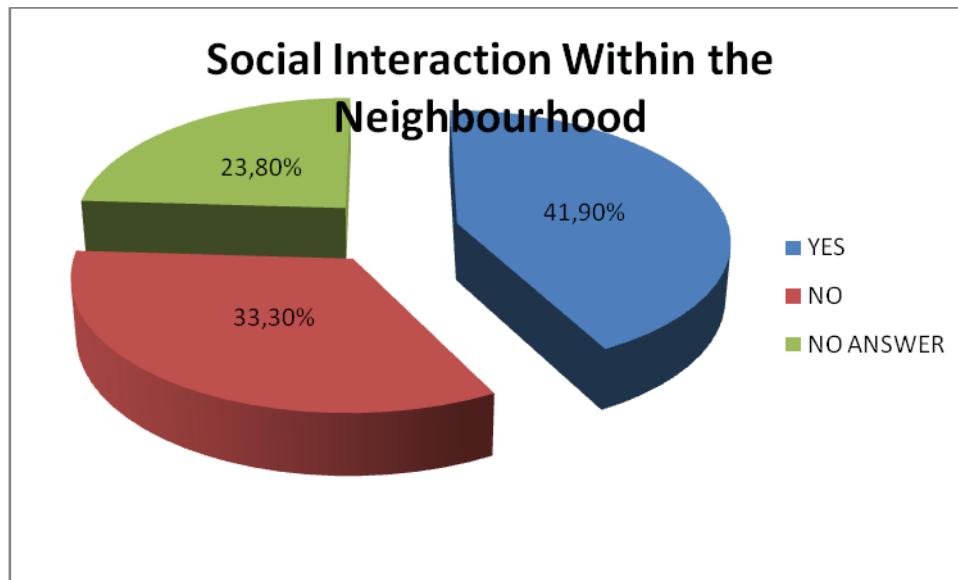


Fig. 7. Social Interaction within the Neighbourhood

Conducting from the answers, the social interaction is more stable in the medium and lower density compared with the higher density. In the medium and lower densities, the social interaction emerges from only neighbourhood relationships. However in the higher density the social interaction emerges from the recreational facilities and opportunities. The recreational spaces around the higher density used quiet a lot. These activities enhanced the social interaction. (Fig.7)

The social interaction is generally expressed by regular neighbour and friend visits, greeting, and mutual respect. There is a strong relationship between neighbors and friends and recreational spaces considered as an important regular meeting place for women. (Fig.8)

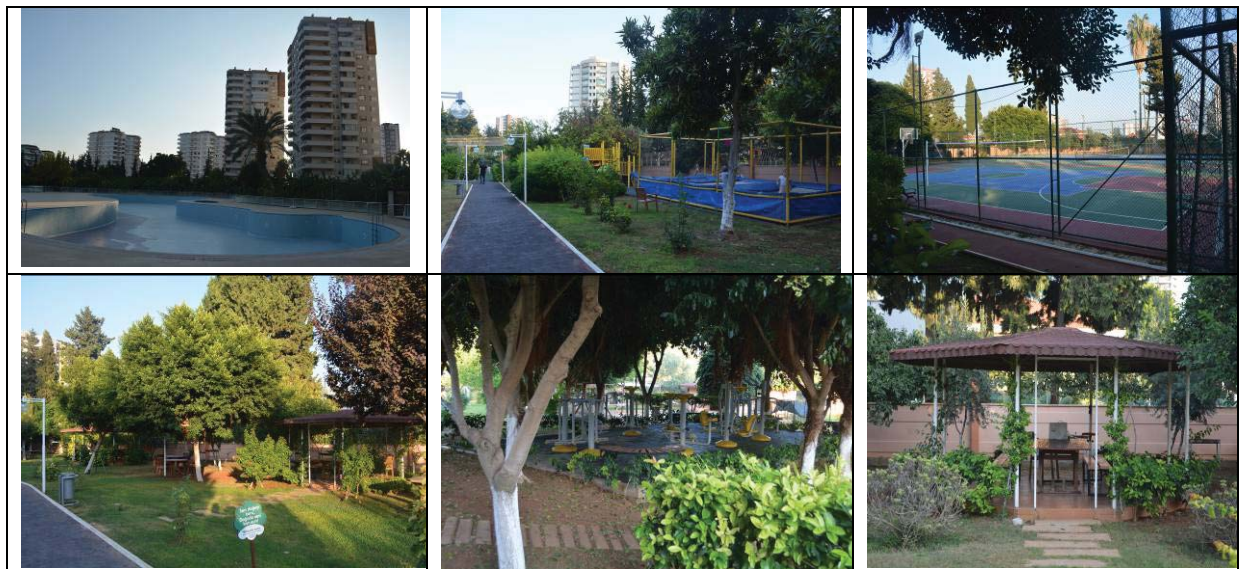


Fig. 8. Some views from the higher density.

'Sense of safety and security' is another sustainable community indicator. These two concepts, in fact, indicate two distinctive meaning. Safety refers to more physical understanding in terms building's structural, constructional and non-structural components

whereas security refers to more judicial concepts such as burglary and assault. These are assumed as complimentary and important parts for developing community sustainability.

Community members need to feel safe. Feeling safe and secure is required not only for the psychological health of the community members, but also for the neighbourhood vitality. The level of crime and anti-social behaviour in a neighbourhood need to be decreased and community-friendly policies are required in order to develop sustainable communities (Long & Hutchins, 2003). In addition, Long and Hutchins (2003) claim that the fear of crime is more widespread than the experience of crime; this view asserts that both issues need be taken into account in an effective assessment process for sustainable places. If the fear of crime is high among a community, the resident's satisfaction level tends to dramatically decrease. Residents' desire to live in environments which provide many opportunities also indicates living in safe and healthy environments in which they can bring up their children peacefully (Salvaris & Wiseman, 2004).

According to Newman compared the level of crime among buildings with different heights revealed that lower buildings had potentially low crime levels (Newman, 1996; Colquhoun, 2004). Newman's analysis particularly focused on storey, size, scale, public area, open space, and degree of ownership and responsibility of the public houses (City of Virginia Beach, 2000).

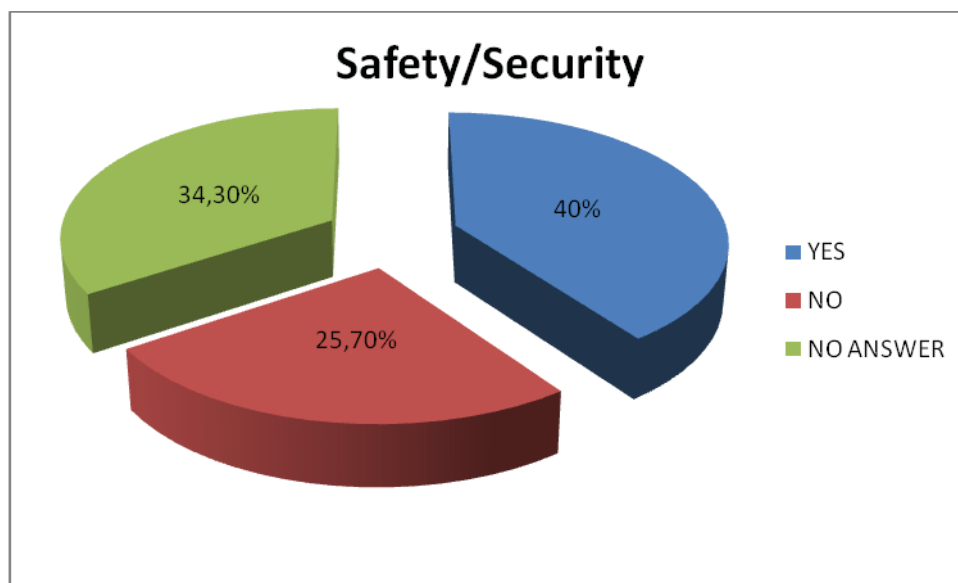


Fig. 9. Safety/Security

Assessing the findings on satisfaction with the neighbourhood, % 45,7 respondents are happy with their home and neighbourhood.

Table 1. Housing Type and Satisfaction within the home and Neighbourhood

Type	I will move	No answer	Maybe I can move	I don't think to move	Not sure	Total
Lower	6 5,7%	0 0%	14 13,3%	21 20%	6 5,7%	47 44,8%
Medium	3 2,9%	0 0%	3 2,9%	5 4,8%	5 4,8%	16 15,2%
High	4 3,8%	2 1,9%	6 5,7%	22 21,0%	7 6,7%	41 39,0%
Total	13 12,4%	2 1,9%	23 21,9%	48 45,7%	18 17,1%	105 100%

The residence satisfaction related to the neighbourhood, the length of the dwelling period in the same neighbourhood/housing estate, the presence of common places for neighbourhood interaction, the reason(s) of living preferences in this neighbourhood/housing estate, the proportion of people to the overall population in the neighbourhood who are concerned about and aware of the community problems, the sense of optimism about the future of the neighbourhood or district, the level of social interaction and meeting with friends and neighbours (social network) all become important measurement criteria of the sense of community and social interaction levels among the residents of a neighbourhood and housing estate.

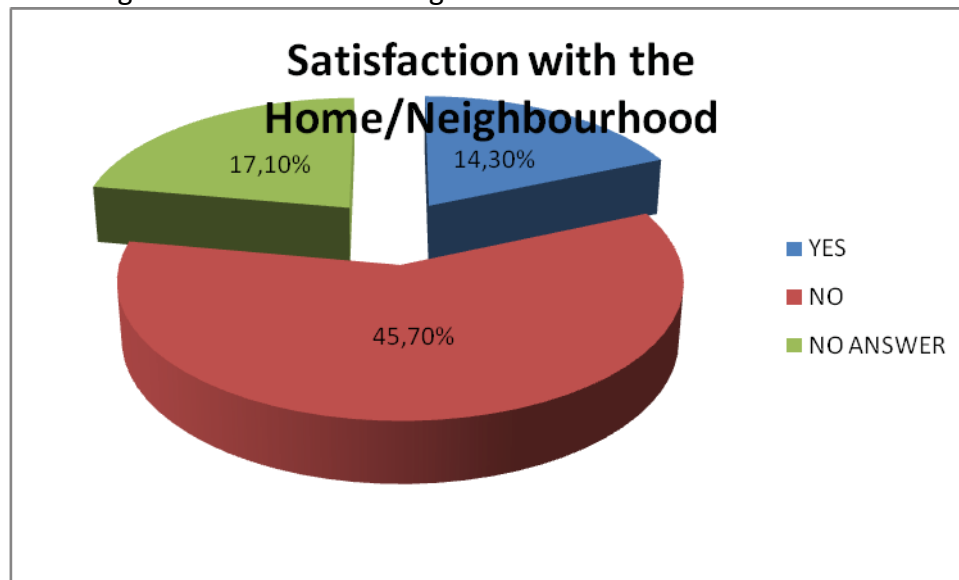


Fig. 10. Satisfaction with the Home/Neighbourhood

## Conclusion

This paper contributes to the growing literature on social sustainability of developing countries of cities, at the neighbourhood scale. In this research we selected the overarching dimensions of urban social sustainability mentioned by Dempsey et.al. (2011) as social equity and the sustainability of community. In order to explore the social sustainability at the neighbourhood level we examine 6 factors such as access to local services, recreational opportunities, open space, pride in and attachment to neighbourhood, safety/security, satisfaction with the home/neighbourhood.

Cities are getting more and more over-crowded and within this, the knowledge of tall building (higher densities) design begins to be a different concept; a solution for minimum land-use and maximum use of capacity of the building for inhabitants. The city alike has a requirement to provide and sustain this social growth and development of needs. Using data from the 3 case study neighbourhoods of different densities (higher, medium and lower) and built forms within the Mersin Metropolitan region, findings suggested that the relationships between urban form, density, housing type and selected social sustainability outcomes were different from the developed countries of the cities.

## References

- Barton, H. (2000). Conflicting perceptions of neighbourhood. In sustainable Communities: the potential for Eco-Neighbourhoods, Barton H (ed.). Earthscan: London:3-18.
- Bramley, G., Dempsey, N., Power, S., Brown, C., Watkins, D. (2009). Social Sustainability and Urban Form: Evidence from five British cities. *Environment and Planning A*, 41, pp. 2125-2142
- Bramley, G., Power, S. (2009). Urban Form and Social Sustainability: the role of density and housing type. *Environment and Planning B*, 36, pp.30-48.
- Burton, E. (2000). The potential of the compact city for promoting social equity. In Achieving Sustainable Urban Form, Williams K, Burton E, Jenks M (eds.). Spon: London: 19-29.
- City of Virginia Beach, M. C. (2000, January 20). *Crime Prevention through Environmental Design: General Guidelines For Designing Safer Communities*. Retrieved December 25, 2012, from Humanics Ergonomics: <http://www.humanics-es.com/cpted.pdf>
- Colquhoun, I. (2004). *Design out Crime: Creating Safe and Sustainable Communities*. Oxford: Elsevier.
- Dave, S. (2008). *High Densities in Developing Countries: a Sustainable Solution?*. PhD. School of Architecture, Oxford Brookes University, Oxford.
- Dave, S. (2011). Neighbourhood Density and Social Sustainability In Cities of Developing Countries. *Sustainable Development*, 19, pp. 189-205)
- Dempsey, G., Bramley, G., Power, S., Brown, C. (2011). The social Dimension of Sustainable Development: Defining Urban Social Sustainability. *Sustainable Development*, 19, pp. 289-300.
- Gehl, J. (2001). *Life Between Buildings: Urban Public Space*. Arkitektens: Copenhagen.
- Long, D., & Hutchins, M. (2003). *A Toolkits of Indicators of Sustainable Communities*. Retrieved September 30, 2011, from The Housing Corporation and the European Institute for Urban Affairs: [http://www.ljmu.ac.uk/EIUA/EIUA\\_Docs/A\\_Toolkit\\_of\\_Indicators\\_of\\_Sustainable\\_Communities.pdf](http://www.ljmu.ac.uk/EIUA/EIUA_Docs/A_Toolkit_of_Indicators_of_Sustainable_Communities.pdf)
- Lynch, K. (1960). *The Image of the City*. MIT Press: Cambridge, MA.
- Newman, O. (1996). *Creating Defensible Space*. Retrieved December 12, 2012, from Defensible Space: <http://www.defensiblespace.com/start.htm>
- Polese, M. And Stren, R. (2000), (Eds.), *The Social Sustainability of Cities: Diversity and the Management Change*, University of Toronto Press, Toronto
- Relph, E. (1976). *Place and Placeness*, Pion: London.
- Salvaris, M., & Wiseman, J. (2004, February). *Mapping community Wellbeing: Using Community Wellbeing Indicators to Choose Goals and Measure Progress*. Retrieved June 18, 2011, from Anew NZ: <http://www.anewnz.org.nz/page.asp?id=1172>
- Warpole, K. (2003). The social dynamic. In *Urban Villages and the Making of Communities*, Neal P (ed.). Spon: London. Pp. 118-131.



# Emergent Trends in Architecture and Urbanism in Modern Cairo: Shifts in the Built Environment

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**Abstract:** This paper examines the shifts and transformations of the different built environments within Greater Cairo's urban agglomeration and argues that shifts and transformations are inevitable in order to achieve sustainability, especially social sustainability in the urban context. The methodology adopted by the research is based on historical facts, comparative analysis and field studies.

It starts out by depicting a quick image of modern Cairo, while highlighting the shifts and transformations that inevitably occurred in the built environment over time. New Cairo City- to the east of Greater Cairo- is taken as an example of these contemporary shifts and transformations, demonstrating the problem of unsustainable urban development and concentrating on the lack of social sustainability. At the end, an approach towards a solution to achieve social sustainability within the urban context is discussed.

**Keywords:** shifts, transformations, built environment, New Cairo City, social sustainability

## Introduction

At the beginning, I would like to briefly highlight the definition of social sustainability. According to the Western Australia Council of Social Services (WACOSS): *"Social sustainability occurs when the formal and informal processes; systems; structures; and relationships actively support the capacity of current and future generations to create healthy and liveable communities. Socially sustainable communities are equitable, diverse, connected and democratic and provide a good quality of life."* Another definition has been developed by Social Life, a UK-based social enterprise specialising in place-based innovation. They define social sustainability as *"a process for creating sustainable, successful places that promote wellbeing, by understanding what people need from the places they live and work. Social sustainability combines design of the physical realm with design of the social world – infrastructure to support social and cultural life, social amenities, systems for citizen engagement and space for people and places to evolve."* (Woodcraft et al., 2011). In light of these definitions, and after the shifts and transformations of modern Cairo are examined in the following section, social sustainability will be briefly assessed in relation to these shifts and transformations, with a concentration on New Cairo City.

## Shifts and Transformations of Modern Cairo

This section aims at depicting a quick image of modern Cairo (since 1798), while highlighting the shifts and transformations that occurred in the built environment over time.

Cairo is a dynamic city that has been shaped by distinct urban-fabric-accumulations over the years. Since this part concentrates on modern Cairo, the development of the city will be investigated starting 1798, when the French invaded Egypt for three years. The French invasion was like a spark of Light; Egyptians were confronted with the full impact of Western civilization. Then came the Rule of Muhammad Ali from 1805 till 1848, during which the foundations of modern Egypt were truly laid. Khedive Ismail took over the rule of Egypt, between 1863 and 1879. He was educated in France himself and therefore, it came as no surprise that the construction of a whole new European Cairo was undertaken during his time.

At the time, the Mukkatam hills to the east had prevented the expansion of the city in that direction, and the Nile had been retreating to the west, leaving behind low land that had been filled and stabilized in order to make way for the new urban expansions. Thus, during the Rule of Khedive Ismail, a new Europeanized quarter was built to the west of the old, traditional city. He had met Baron Haussmann in Paris at the “Exposition Universelle” (1867) and decided that what had been done to Paris must be done for Cairo within two years to celebrate the opening of the Suez Canal. And so, a Paris along the Nile has been built: Wasat Al-Balad/ Downtown Cairo, with a well-defined road system and a clear distinction between city blocks. In 1882, under the British Occupation, a unique colonial city had started developing. With the mechanization in public transport, a new electric tram system encouraged the building of suburban residential quarters in the first part of the 20th century: Heliopolis to the northeast of the city (in 1905, Nubar Pasha and Baron Empain were given the right to develop an area of 5000 hectares into a residential community with suitable facilities and utilities). Taking a closer look at Heliopolis, it is worth noting that the district had been planned and constructed, in 1907, as a garden satellite town- designed in the latest manner of British town planning of Ebenezer Howard’s Garden Cities- ten kilometres from the centre of Cairo in the north-eastern direction. It is worth mentioning that not only has the transportation link allowed the growth of Heliopolis itself, but it has also resulted in the emergence of a continuous band of urban settlements stretching all the way between Wasat Al-Balad and Heliopolis. Between 1882 and 1937, the population of Cairo increased from 374,000 inhabitants to 1,312,000: an increase of 250% over fifty years, when the increase during the previous 84 years (from 1798 to 1882) had only been 26%. By 1950, the city’s economy had enjoyed a boom and it was ready to expand at a scale never before seen in history- (Abu-Lughod, 1971). By then, large migrations from the countryside had started taking place and until the early 1960s the city expanded substantially through state-aided social/ public housing projects, especially after the 1952 revolution- (Sims, 2012).



Figure 1. Cairo in the early 19th century and in the second half of the 19th century, showing the development of Wasat Al-Balad. Sources: left map: Scharabi, 1989; middle map: Elmokadem, 1997; picture: Scharabi, 1989

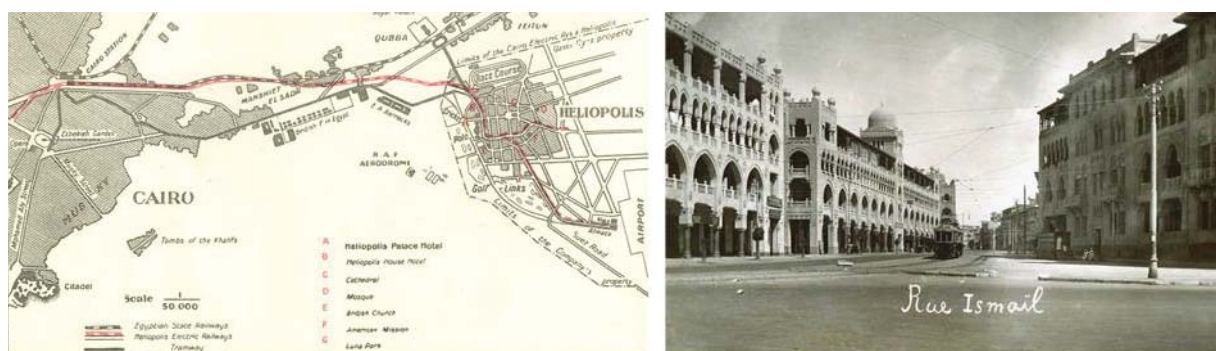


Figure 2. The development of Heliopolis in the early 20th century- Source: Heliopolis Company Book, 1969



By 1960, under Nasser's Regime, 60% of Cairo's population growth resulted from natural increase, while the remaining 40% resulted from internal migration. At that time, a number of informal areas had begun to emerge, due to the rapid increase in population and the large numbers of internal migrants. One of the most important effects of the military disaster of 1967 and of the 1973 war, as well as of continued hostilities along the Suez Canal was a marked increase in the population of Cairo.

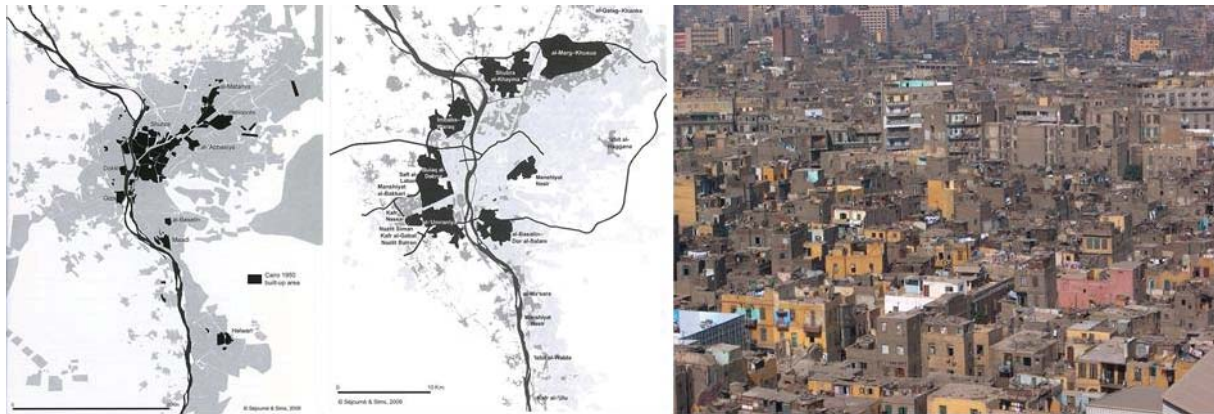


Figure 3. The built-up area in 1950 in comparison with the built-up area in 2009; and large informal settlements in 2008- Sims, 2012

Between half a million and a million Egyptians were evacuated from the war zone, and although some were relocated in other urban centres and in areas of land reclamation, many of them have since then settled in Cairo. In many quarters of the city there was evidence of additional crowding as families had doubled up to make room for relatives from the Canal towns (Abu-Lughod, 1971). The June 1967 war stopped all of Cairo's planned urban expansions and Egypt rapidly shifted to a wartime economy; this continued until the October 1973 war. However, at that time, informal settlements continued to grow- (Sims, 2012).

Nasser's policies were followed in the mid-1970s by President Sadat's *infitah*, or Open Door Policy, which had deep effects on the urban development of Cairo. *Madinat Nasr* (Nasr City), a huge, 7000-hectare concession on state desert land, directly east of Al-Abbasiya and south of Heliopolis, became the most significant city extension, based on the concept of the neighbourhood unit. The project had actually been launched in 1958, but because of the war interruption, it only really took off in the mid-1970s- (Sims, 2012). By that time, plans to execute new urban communities to the east and to the west of Cairo have been unavoidable due to the numerous problems the city was facing because of the rapid increase in population.



Figure 4. Nasr City and the concept of the neighbourhood unit

From 1986 to 1996, Greater Cairo, as a whole, witnessed a significant slowing of its population increase, registering only 1.9% annual growth. However, informal settlements were still growing substantially, reaching over 5.4 million inhabitants. In terms of population shifts in the existing city, the most significant phenomenon was the depopulation of the older, especially historic districts in central Cairo- (Sims, 2012).

In the 1990s and 2000s, new urban communities have seriously taken off, representing an important shift in the development of the urban agglomeration of Cairo, which will be clearer in the next part, which discusses New Cairo City as an example. At that time, there have been a number of improvements and transformations, especially in terms of infrastructure: the ring road was built in stages, the 26th of July corridor to the west and more flyovers have been constructed- (Sims, 2012). In 2006, Greater Cairo's population had reached almost 16 million inhabitants and in 2012, it had reached almost 18 million, with massive population increase in informal settlements.

From the previous examination, it is inevitable to acknowledge the existence of a Cairo mosaic- (Abu-Lughod, 1971). We have seen the morphogenesis of planned districts in the existing city, such as Wasat Al-Balad, Heliopolis and Nasr City, influenced by international paradigms, existing at the time of their formation. We have seen their expansions and the evolution of other planned districts around Cairo. Around 1960, informal settlements had started to evolve due to the large numbers of internal migrants and the inability of the government to meet the housing demand, especially after the evacuation of the Suez Canal Region in 1967.

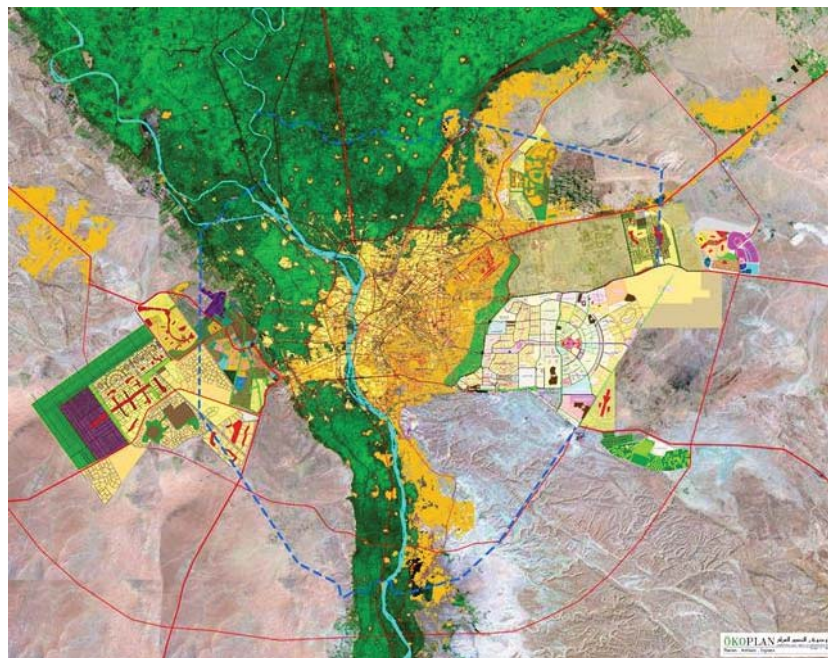


Figure 5. Greater Cairo Region in 2009, including the new urban communities to the east and to the west of the ring road- Source: Ökoplan Engineering Consultations, Cairo

Historic districts and central areas have lost inhabitants, while other planned districts, such as Heliopolis and Nasr City, have been densified and have transformed over the years. At the same time, informal settlements have continued to grow in-between planned districts and the urban agglomeration has greatly densified. In addition, new urban communities to the east and to the west of Cairo have started to emerge. Taking a closer look at the transformations that occurred in Wasat Al-Balad, Heliopolis and Nasr City, it is observed that



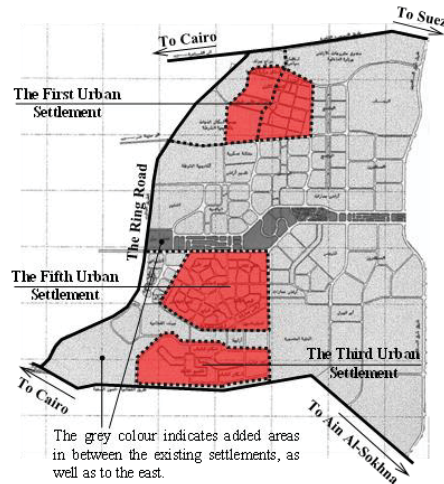
the first lost a big part of its glamour and has become out-of-date; and although its buildings have been changed, one can perceive through their now-shabby appearances the traces of a better past.

The second has always been striving to physically accommodate in order to go along with the prevailing trend, sometimes at the expense of tearing down valuable houses and replacing them by large apartment buildings that would bring about more revenue. The third lost its initial socialist direction and has become completely under the control of the market, with mostly high-rise buildings that demonstrate all kinds of mixed-up architectural styles, and which accommodate all sorts of activities that also go with the flow. Presently, the main goal is the achievement of maximum revenue from real estate projects on behalf of private investors. This fact has greatly changed the direction of urban development within Heliopolis and Nasr City in particular. One may actually say that urban development within these two districts is now moving, more or less, on the same track. Whereas, Wasat Al-Balad is continuously repelling inhabitants. From these quick observations, one could conclude that Wasat Al-Balad has not been socially sustainable over the years, while Heliopolis has been and currently, Nasr City is starting to lose its inhabitants, who are moving to other areas that better serve their needs. Social sustainability was mostly attained in Heliopolis because, from the very beginning, its built environment was conceived based on social categorisation, as well as a hierarchy of social classes and communities. Therefore, all social categories were able to find their needs within its real-estate market. During its gradual urbanisation, the market dynamics took over and all social communities mingled based on their socio-economic levels and incomes within their social classes, which in turn, maintained a good level of social sustainability over the years- (Mahmoud, 2010).

### **New Cairo City: A Representation of the Contemporary Shifts and Transformations in the Built Environment of Greater Cairo**

In 1993, ten years after the 1983-General Planning of Greater Cairo Region was prepared and due to the numerous problems that resulted from the rapid increase in population and internal migration, lots of investments and construction activities have been directed to the new urban settlements located to the east and west of Cairo. The result was an increase in the areas designated for new urban settlements and a reconsideration of their distribution around Greater Cairo; in particular for the first, third and fifth urban settlements, lying to the east of the Ring Road, and included between the Cairo-Suez Road to the north and the Cairo-Ain Al-Sokhna Road to the south. These three small urban settlements have, since then, been contained within the borders of one large urban settlement called: New Cairo City; and the in-between areas have been divided and sold to individuals, as well as to investment companies that established large residential and recreational projects on them. In addition, new areas have been added to the east of the three urban settlements, designated for residential use- (El Khorazaty, 2006). The combination of the first, third and fifth urban settlements, as well as the filled-up, in-between areas and the added parts to the east had formed New Cairo City, which then covered an area of approximately 115 km<sup>2</sup> (11,500 hectares) and was planned to accommodate 1.02 million inhabitants- (El Khorazaty, 2006). In 1998, an extension had been planned to the east of the previously laid out urban settlement, increasing the area of New Cairo City to reach 188.16 km<sup>2</sup> (18,800 hectares), to accommodate, in total, approximately 4 million inhabitants. From the beginning, New Cairo City has been meant to become a center of regional services, including office parks, as well as recreational, commercial and educational activities.





The first, fifth and third urban settlements, as well as the in-between amalgamating areas, in addition to added areas to the east, all together formed New Cairo City as planned in 1993, with an area of approximately 115 km<sup>2</sup> and estimated to accommodate around 1.02 million inhabitants.

Figure 6. The emergence of New Cairo City- Source: El Khorazaty, 2006

Referring to Figure 7, and through field observations, urban development areas in New Cairo City could be divided into seven groups:

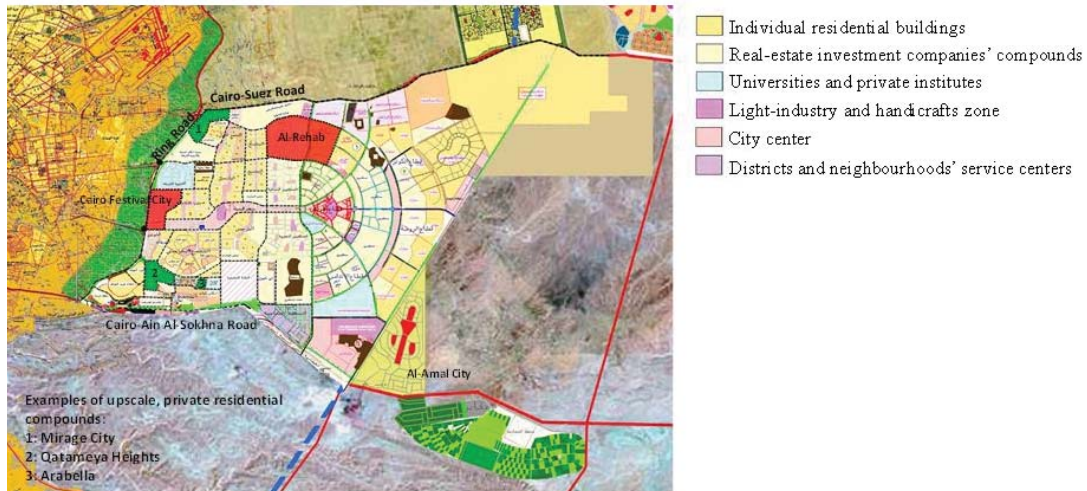


Figure 7. New Cairo City master plan, showing the residential areas, the neighbourhoods and the hierarchy of service centers- Source: Ökoplan Engineering Consultations

### **Group 1: Private Gated Residential Compounds**

These are developed by private real-estate investment companies on fairly large parcels of land. They are fenced with strong security controls at their entry gates. Examples are: Qatameya Heights, Mirage City, Arabella, Dunes, Mivida and others in the northern and southern investors' areas, many of which are currently under construction.



Figure 8. Private gated residential compounds



### ***Group 2: Semi-Private Gated Residential Compounds***

Al-Rehab City is an example of these compounds. It is a gated community, owned by a private real-estate development company and comprises various residential types, as well as many services (commercial centers, entertainment areas, a sports club, schools...) open to the public, which means that people are allowed to enter easily, with minor security checks.

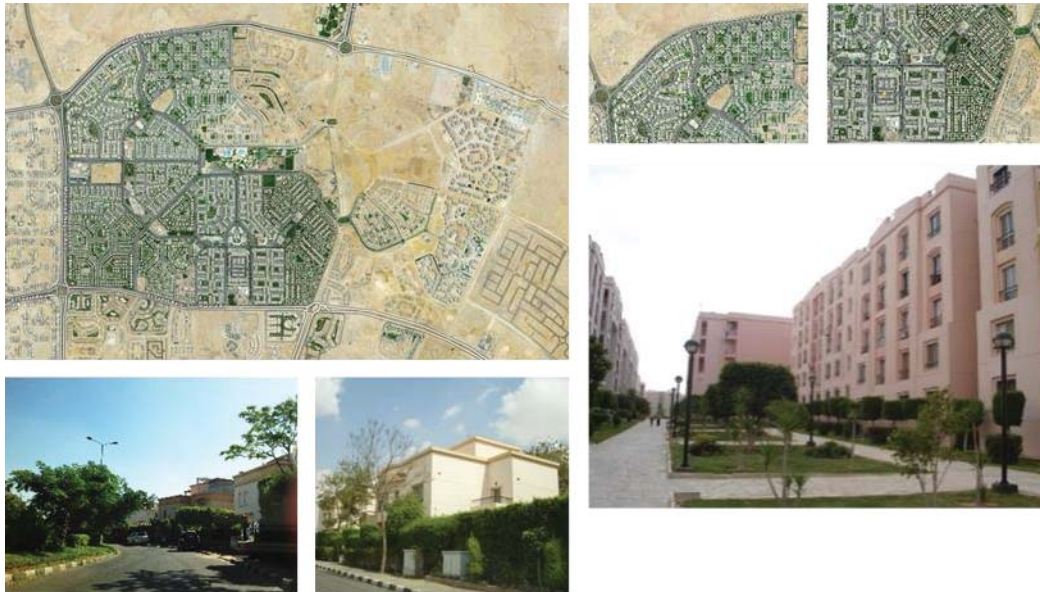


Figure 9. Semi-private gated residential compounds

### ***Group 3: Public Housing***

This is the kind of affordable housing provided by the government and can be found in the origins of the 1st, 5th and 3rd settlements.



Figure 10. Public Housing

### ***Group 4: Private Individual Residential Buildings***

These are the residential buildings constructed privately by individuals and are found on the plots, designated for housing, outside gated residential compounds.



Figure 11. Private individual residential buildings

### ***Group 5: Services and Amenities***

These are the service buildings constructed privately or by the government on individual plots designated for amenities within the city, including mosques, schools, shops, hospitals...etc.



Figure 12. Services and amenities

### ***Group 6: Individual Office Buildings***

These are office buildings, owned by private companies, on individual plots, designated for offices within the city.



Figure 13. Individual office buildings

### ***Group 7: Large Mixed-Use Developments***

These are developed by private investors on fairly large parcels, where mixed-use activities are accommodated, including office parks, retail, shopping malls and entertainment facilities. Examples of these complexes are found along the ring road, as well as on road 90, such as, Cairo Festival City and “Downtown”. It is worth mentioning that many others are being planned.



Figure 14. Large mixed-use developments



It is thus clear that New Cairo City represents a shift in the urban development of Greater Cairo as a whole, which is clear in the emergence of new land uses and activities: ones that weren't there in the Existing City. These are mainly represented in gated residential compounds, large retail and entertainment complexes, as well as office parks and large mixed-use developments that belong to one investor. Also, the way the city is being developed is different from what occurred over more than 1000 years in the Existing City. It is worth mentioning that New Cairo City is still in the development process and has not yet reached its planned population targets. Despite this, the growth of New Cairo City over the past 20 years has not been incremental. On the contrary, the government has always been providing the main road and infrastructure networks and has been selling parcels to investment companies, as well as individuals to develop their own projects, according to the building regulations and codes of New Cairo City. As a result, the whole urban settlement has spread out and has long been defined over an expanse of desert land that is approximately 15 km wide, to the east of the ring road and 12 km long, from the Cairo-Suez Road to Al-Ain Al-Sokhna Road: a land area, not far from that of the Existing City. This has taken place, at least over the past ten years, with many parcels left empty, until the real-estate market dynamics allow their development.

Another observation is that the physical plan of the city is not flexible enough to accommodate changing demands and sustainability measures.

"The planning documents that have been produced for New Cairo City include numerous items that are concerned with land-use allocation plans, zoning plans, the hierarchy of street systems, programs of provided services, numbers of neighbourhoods and residential units, residential densities, floor-to-area ratios, built-up areas, and permitted heights. There is not once a mention of urban design guidelines or design controls. The documents do not by any means tackle the desired architectural styles of buildings or the aspired quality of the urban environment"- (El Khorazaty, 2006).

Taking a look at the façades of buildings, it is noticed that there is a lack of flexible urban and architectural design guidelines and that, within the parcels, projects are developed through a process of almost "complete randomness"- (El Khorazaty, 2006).

In order to achieve sustainable urban development, the three pillars of sustainability have to be accommodated in the planning and design of the city. Through field observations, it is clear that the city is somewhat economically sustainable, with all the services it provides- including offices, large commercial/ retail complexes, schools, universities and others- and accordingly the job opportunities it creates. Moreover, within New Cairo City, there is a light-industry/ handicraft zone, providing an economic base. In addition, it is adjacent to the industrial area of Al-Amal City to the southeast. Moreover, environmental sustainability is not achieved either on the urban scale or on the building scale, especially that it is not a building requirement in the development of any project- it is an issue left for the developer to decide. Likewise, the physical environment does not offer social sustainability. This is clear from the following observations: (the following observations are based on the criteria highlighted in the definition of social sustainability at the beginning of the paper: *"a process for creating sustainable, successful places that promote wellbeing, by understanding what people need from the places they live and work. Social sustainability combines design of the physical realm with design of the social world – infrastructure to support social and cultural life, social amenities, systems for citizen engagement and space for people and places to evolve."*- (Woodcraft et al., 2011).

- The low population densities within the city.

- The lack of communal public spaces that don't involve retail or any other "paid" services. This, in turn, causes deficiencies in social interactions and in the creation of social networks in the community.

- The lack of public transport connections within the city; it is worth mentioning that public transport connections to the "Existing City" are also non-existent.

- The existence of low safety measures for pedestrians in wide streets, designed for high-volume traffic with minimal pedestrian facilities. The city is not exactly walkable because of poorly designed and poorly constructed streets: there is a shortage of sidewalks and pedestrians face difficulties in crossing streets. The problem might be simpler inside the neighbourhoods, where streets are smaller and the scale is more intimate.

- The existence of gated residential compounds: a phenomenon that deliberately separates a sector of the people living in the city from the others, causing an incision in the society. Nevertheless, in case of gated compounds, safety and social interactions do exist. In addition, people living there have a better sense of place: they know and feel that the place belongs to them: a fact that makes social sustainability more effective.

Finally, it is worth pointing out that because of the lack of social sustainability, the people living in New Cairo City will transform their surrounding built environment by themselves, not according to a general framework or a collective vision, which will result in developing the city randomly instead of incrementally building up an organized complexity that is responsive to transformations over time.

### **Conclusion: An Approach towards a Solution to achieve Social Sustainability within the Urban Context**

Through the previous analysis of both the Existing City and the New Urban Communities, it has become clear that shifts and transformations in the built environment are inevitable in order to achieve sustainability, especially social sustainability. We have seen the planned districts in the Existing City being densified through vertical and horizontal extensions and the façades of buildings changing in order to try to accommodate social, as well as environmental transformations. We have also seen that changes in economic activities within some districts have caused depopulation and shifting the inhabitants to other districts, which are more privileged economically.

It is also important to envision these planned districts are part of the whole city of Cairo, sharing much in common with it, but also retaining- or at least trying to retain- their own unique characteristics. The present structure of the districts is very much tied to past historical developments. Therefore, it should be true to assume that if one knows the period in which each of them was first settled, as well as the social backgrounds of the earlier residents and any special modifying influences, particularly economic and environmental that made an area more or less responsive to change, one should be able to understand and predict many elements of each district's physical transformations.

It has also been observed that informal settlements have emerged in response to socio-economic factors that occurred in the city of Cairo over the years and that their existence- however negatively perceived- has actually sustained the metropolis and has allowed the large numbers of inhabitants to find the shelter, which the government has not been able to provide for years. In some cases, these informal settlements even provide job opportunities.

However, because of the numerous problems found in informal settlements, and the rapid urbanization in Cairo, the government has shifted the built environment towards new urban communities, for which clear physical master plans have been developed and have



mostly been implemented, however, lacking many aspects of sustainability. However, in order to head towards sustainable urban development, the three pillars: economic, environmental and social should be accommodated in cities. The government and the people should work cooperatively to include environmental and economic aspects in building laws, regulations and codes. The first two pillars (environmental and economic) are not the focus of this paper, but the concentration here is on the social aspects, which- if not tended to- inevitably cause unwanted transformations.

After briefly examining New Cairo City, it has become clear that social sustainability has almost not been achieved for the city as a whole. In a recent report, created in collaboration between The Berkeley Group, Social Life, and Prof. Tim Dixon from the University of Reading, entitled *Creating Strong Communities: How to Measure the Social Sustainability of New Housing Developments*, it is stated that:

“Social Sustainability is about people’s quality of life, now and in the future. It describes the extent to which a neighbourhood supports individual and collective well-being. Social sustainability combines design of the physical environment with a focus on how the people, who live in and use the space relate to each other and function as a community. It is enhanced by development, which provides the right infrastructure to support a strong social and cultural life, opportunities for people to get involved, and scope for the place and the community to evolve.”- (Bacon, Cochrane, & Woodcraft, 2012)

From the above statement, it is clear that in order to achieve social sustainability in an urban context- in this case, New Cairo City is taken as an example- urban planning should address and enhance the following aspects:

- Public participation in decision-making should be adopted when planning areas in the city. This allows the people to develop a sense of belonging to a place: they know it is theirs and they act accordingly.
- Through public participation methods and through observing the places where normally there are large volumes of pedestrians, it can be decided where to develop communal public spaces, including- but not limited to- parks, in order to start establishing social networks in the community.
- Population densities should be increased according to a collective vision and based on agreed upon guidelines.
- Public transport networks within the city must be established so as to achieve better connectivity.
- Suitable sidewalks and safe crossing points must be established to give pedestrians the required safety, security and ease to walk through the city.
- It is also suggested to design bicycle lanes, adjacent to car lanes to provide another environmental-friendly mode of transportation.
- Gated residential compounds should be minimised.

It is also suggested that cooperative organizations carry out the projects within the city, since a “co-operative” is a form of organization that is owned and democratically controlled by its shareholders and members. A co-operative is also known as a mutual organization or a “co-op”, run for the mutual benefit and support of its members or the promotion of a specific purpose or a social benefit.

Transformations over the years are unavoidable, but when they happen according to a certain collective vision, the result is organized complexity. It is thus important to allow the people to participate- with the regulating body- in a collective vision for the place where they

are to live. This gives the community a kind of stability, pride and a sense of place, which - in turn - guarantees a good quality of life and social sustainability.

## References

- Abu Lughod, Janet (1971). *Cairo: 1001 Years of the City Victorious*. Princeton, New Jersey, USA: Princeton University Press.
- Elmokadem, Ashraf (1997). *Die Kolonialarchitektur des historischen Wohn- und Geschäftsviertels "Wasat Al-Balad", Kairo*. München: CS Press.
- Mahmoud, R. A. (2010). *Heliopolis: The metamorphosis of a garden city into an urban district*. EUE Les Editions Universitaires Européennes. Berlin, 240 P. (Book in French).
- Raymond, André (translated by Willard Wood - 2001). *Cairo: City of History*. Cairo, Egypt: the American University in Cairo Press.
- Scharabi, Mohamed (1989). *Kairo: Stadt und Architektur im Zeitalter des europäischen Kolonialismus*. Tübingen: Verlag Ernst Wasmuth.
- Sims, David (2012). *Understanding Cairo: The Logic of a City Out of Control*. Cairo, Egypt: the American University in Cairo Press.
- Bacon, N., Cochrane, D. and Woodcraft, S. (2012). *Creating Strong Communities*. London: the Berkeley Group.
- El Khorazaty, Tamer (2006). *Urban Design Guidelines: A Solution for Rectifying the Visual Disorder of New Cairo City*. A paper published in the scientific journal of Hochschule Nuertingen, Germany.
- Woodcraft, Saffron et al. (2011). *Design for Social Sustainability: A Framework for Creating Thriving New Communities*. London, UK: Social Life. [www.social-life.co](http://www.social-life.co)
- Heliopolis Company Book, Egyptian Surveying Authority (ed.) (1969). *The Suburb of Heliopolis: its present and its future (in Arabic)*. Cairo: Heliopolis Company for Housing and Development and the Egyptian Surveying Authority.
- [https://en.wikipedia.org/wiki/Social\\_sustainability](https://en.wikipedia.org/wiki/Social_sustainability)

# Smart Solutions in New Cities as main actors in Regenerative Urbanism: "The Creation of Resilient Cities through Circular Urban Metabolism and decreasing Ecological Footprints"

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**Abstract:** The urbanisation process has- since the industrial revolution- marked the planet earth with several grave phenomena, such as climate change and the loss of biodiversity to mention only a few. This resource-intensive process affects the world's ecosystems and is mainly demonstrated through ecological footprints, which must be decreased in order for cities to become more environmental-friendly. Regenerative urban development is considered an effective concept that could help with decreasing ecological footprints and thus, restoring damaged ecosystems. This integrated approach aims at reaching circular systems of resource use instead of linear ones. This is accomplished through adopting regenerative relationships between cities and their ecosystems, as well as embracing comprehensive, environment-enhancing strategies, whose intentions are not only to sustain existing resources, but also to enhance cities' ecosystems in order to supply resources through circular urban metabolisms. We believe that adopting interrelated smart solutions in new cities could play a major role in attaining an advanced stage of regenerative urbanism.

This paper starts by demonstrating current urbanisation problems and how the ecological footprints of cities are representations of where cities stand in relation to their ecosystems. It then shows how the world is moving on to decreasing ecological footprints through creating resilient cities and adopting circular urban metabolisms, as well as regenerative urban practices, which become more effective and efficient when applied through smart solutions. Examples are given of the relationship between regenerative urbanism and smart solutions, as to how they could be integral parts of the planning process of new cities. For example, such smart solutions could help with the efficient use of renewable energies, with the improvement of waste management systems and with efficiently sticking to the new cities' hinterlands, which ultimately help in reaching suitable ecological footprints that do not exceed the productive land on earth.

**Keywords:** Ecological Footprint, Regenerative Urbanism, Circular Urban Metabolism, Resilient Cities, Smart Solutions

## Introduction: Urbanisation and Ecological Footprints

Today the urban human is the one who leaves traces on the natural environment more than any other species on Earth. These traces mostly affect nature negatively, thus the relationship between humans and their environment is more and more complex. As being the predominant urban species, not all humans question themselves about what they leave behind on the planet earth. Modern cities are the explicit example, as they are characterized by intense human interactions and economic activities that -in many cases- have little or no consideration of the surrounding environment. This is shown through the high levels of resource consumption, and the waste disposal methods that show almost no concern for the consequences.

The industrial revolution was an igniter of a resource-intensive urbanisation process. Consequently, since this event that had shaken the whole world, another phase of climate

change, loss of biodiversity, loss of natural fertility of the farmland, etc. has started. These phenomena are accentuated by modern lifestyles and high consumption of energy and resources in general that have severe consequences on our natural environment. They put all lives on Earth in jeopardy including the human life. This is the main reason that today one of the main concerns is how to tackle this grave problem.

The concept of ecological footprints takes a serious step towards assessing the human impacts on planet Earth's ecosystem. It is simply the amount of land required to support people's lives and lifestyles. More explicitly, it is the measurement of people's impact on the natural environment and is used as a guide to raise people's awareness towards the footprint that communities should adopt in order not to exceed the productive land on Earth. It is worth pointing out that the larger and the richer the city, the more it tends to draw on nature's bounty from across the world rather than its own local hinterland; ecological footprints could be hundreds of times larger than the cities themselves. In an urbanizing world, and as our populations grow and global consumption increases, it is essential that we measure nature's capacity to meet the demands on our planet. Thus, cities need to work on minimising their ecological footprints.

We believe that smart solutions can be main actors in circular urban metabolisms, which will lead to a high degree of regenerative urbanism and resilient cities, and that will- in turn- decrease the ecological footprints of cities, as we are going to clarify later in our research.

## **Research Approach**

The research appropriates a holistic approach that is structured at various levels. Firstly, for us to be able to comprehend how smart solutions in cities can be a main actor in order to attain a high level of regenerative urbanism, the research will be fed by a literature review that encompasses several definitions such as urban metabolism, regenerative urbanism, resilient cities and circular urban metabolism, etc. Secondly, an analytical approach will be adopted through scrutinising different examples of resilient cities that implemented a variety of smart solutions and embraced a circular urban metabolism trend to eventually arrive at a considerable level of regenerative urbanism. Finally, graphic and data analysis will act as the main support to our hypothesis.

## **Literature Review**

The research topic requires the understanding of many terms that are related to the regenerative urbanism domain. We believe that adopting smart solutions in new cities can be a main actor for these cities to be more resilient thus more urbanely and socially sustainable.

### ***Urban Metabolism***

According to "Research Group of the Department of Urbanism at the Delft University of Technology" "Urban Metabolism" is a framework to mock-up a city's complex urban systems' flows as if it functions as an ecosystem. These urban systems include people, water, energy, food, etc. It is used to mainly analyse the effect and the relationship between human activities and the natural environment. It also examines how urban areas function regarding the use of existing resources and infrastructures. These analyses can serve in developing a more sustainable environment on both the urban and social levels. In this notion, the city is considered a living organism whose collective urban metabolism can be traced over more than 150 years (RGDU, 2017).

Recently, the definition of "Urban Metabolism" has been updated by Christopher Kennedy to designate "the sum total of the technical and socio-economical processes that occur in cities, resulting in growth, production of energy, and elimination of waste"(RGDU, 2017). This notion has been used as a tool to analyse and understand the material and energetic exchanges between different cities and the rest of the world. It is basically an attempt to quantify outputs and inputs of different urban systems, as well as their stock and recycling of resources. Moreover it calculates the various flows within an urban environment in the hope of attaining a circular urban metabolism, another term that we will later shed light on in this research.

This concept can be applied to urban design and planning, but first we need to understand and analyse the corresponding infrastructures in the urban environment. These analyses include for example the study of water supply, extraction and purification; solid waste management, separation and collection; energy supply, electricity generations and grid; heat networks, and food supply.

### ***Regenerative Urbanism***

Regenerative urban development is one effective way that could help restore damaged ecosystems, and therefore, decrease ecological footprints. Embracing regenerative development means the initiation of comprehensive strategies for an environmentally enhancing, restorative relationship between cities and their ecosystems, from which they draw resources for their sustenance, moving from linear systems of resource use to circular systems. Thus, the aim is not to merely sustain resources- there is anyway much less to sustain today than there was twenty years ago- but to go beyond that to positively enhance the ecosystems, which provide the resources. It is an integrated approach that sees humans, human developments, social structures, political frameworks and cultural challenges as an inherent part of ecosystems. Globally, there are many examples of good policies and practices for regenerative urban development, including, but not limited to, regenerating soils, forests, watercourses and urban agriculture on the city level. This fairly new practice transforms urban areas into regenerative cities that reduce their dependence on fossil fuels, boost the utilization of renewable energies, improve waste management systems and rely more on their hinterlands, which eventually reduces ecological footprints.

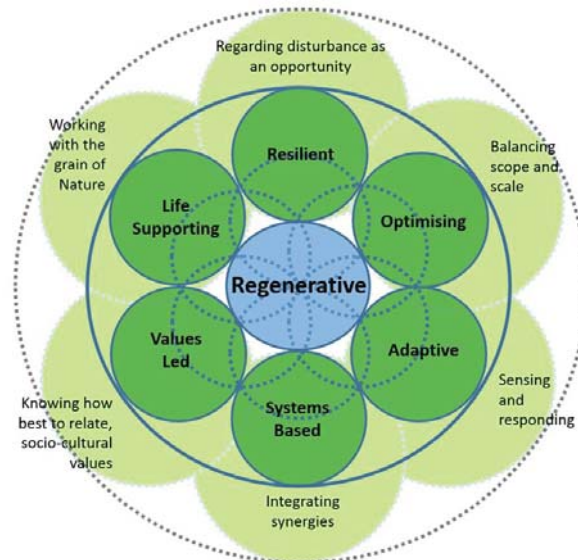


Figure 1. The characteristics of regenerative systems



## Resilient Cities

The concept of resilience was firstly coined during the late 70's and early 80's by specialists in the domain of ecology and psychology to understand various phenomena (CARRI, 2013). Later, the term was used to refer to communities that sustained their core and behaviour in spite of adversity. Moreover, ecology specialists used to term to describe ecosystems that functioned steadily during difficulties. The engineering community adopted the same concept to designate the ability of absorbing and recovering from disasters, especially on the physical infrastructure level (Mahmoud, R., 2016).

In general, the term "City Resilience" reflects the city's ability to preserve itself in the face of emergency, to conserve its core despite daunting challenges (WATSON, B., 2014). It is the ability to become successful, or strong again after facing a difficult situation or event (Longman, 2016). Building resilience in a city is complex work, however cities in the 21st century should imperatively start to function differently. Insurmountable challenges from migration to flooding are facing cities in the time being. In order to concur these challenges, collaboration is required in all existing city sectors that are truly involved in city: governments, institutions, private sectors, communities, etc. (Lipper, B., 2016).

In urban and human sciences, a resilient city means nowadays that this city can face its own challenges. These challenges can be climatic, lack of resources (human, energy or others). Nevertheless, in order for a city to be resilient, at first, it must be able to determine and to better understand the challenges it faces. Moreover, the city has to review its actual abilities to be able to address those challenges. Ultimately, this city, as an organism, should be able to unite people, projects and priorities so they can collectively act on their probable resilience challenges (Lipper, B., 2016). One of the tools that can help cities attain resilience is the "The City Resilience Strategy". The latter is the product of a process that lasts six-to-nine month, during which the city can scrutinize and develop a holistic overview of the challenges it faces. Then it can unite all the mentioned parties to face these challenges. The final product is not a master plan but rather a declaration by this city for prioritizing its intentions to join the building resilience circle (Lipper, B., 2016). In order to obtain this strategy, the city should gather and synthesize and evaluate data to understand how it is already working. It is an ongoing process, not linear but rather iterative one that gathers the community and stakeholders, evaluates and assesses opportunities (Lipper, B., 2016). Throughout this practice, the city should also apprehend where its focus will be and why. Moreover, this process also considers peer learning from other pioneer cities in this domain. Eventually, the city should be able to generate a tailored strategy, or an action plan that contains initiatives and projects, that take into consideration its own strengths and vulnerabilities. This step can also encompass initiated workshops, closer studies in certain areas such as financial and risk issues- see Figure 2.

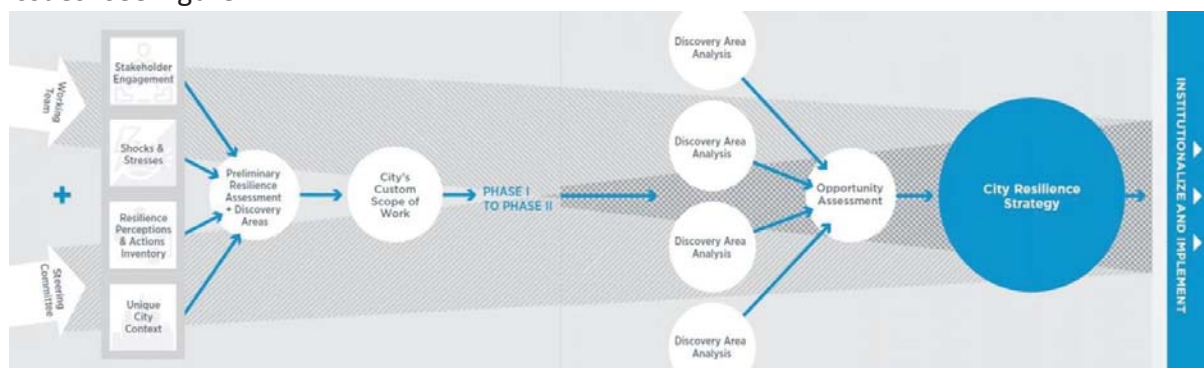


Figure 2. Phases of "The City Resilience Strategy". Source: (Lipper, 2016)

### Linear versus Circular Urban Metabolism

Nature, as an ecosystem, has a zero circular waste metabolism, it means that all outputs by different organisms are recycled back in the system once again (HCU, 2010). This process is the secret of a regenerative, replenished environment. Cities as "eco-technical super-organisms" are similar to nature, in the fact that they transform resources into vital functions through a similar metabolic process (Girardet, H., 2008). Nevertheless, not all metabolic processes, carried out by different cities, are circular like in the case of a natural environment. In fact, the urban metabolism of many cities is rather linear than circular; it means that during this process resources flow through and out of the urban system without worrying neither about their destinations nor about their origins- see Figure 3. More explicitly, in contrast to circular urban metabolism, in the linear urban metabolism, inputs and outputs are largely unrelated: waste gases of different processes are released into the atmosphere, raw materials end up as solid wastes -after manufacturing- and are discharged into rivers; and they are not recycled back into the urban environment. This is why circular urban metabolism- where most of the outputs represent inputs in the environment- is the key to regenerative urbanism and is indispensable for reaching resilient urban systems. This circular system has to be adopted if cities want to assure their long term viability (HCU, 2010). In this matter, nature is the most efficient teacher on how to create a circular metabolic urban system.

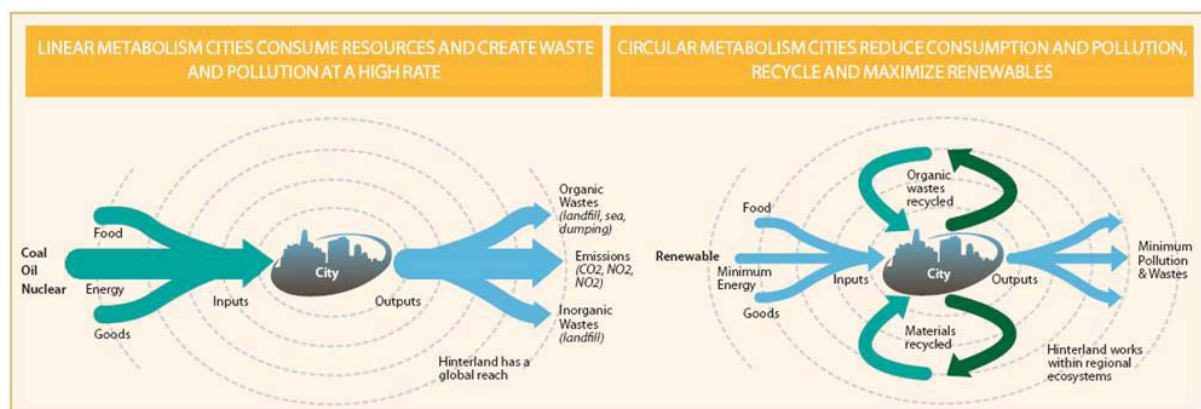


Figure 3. Linear and Circular Metabolism. Source: (Girardet, 2008)

### Smart Cities

Smart cities are those that use information and communication technologies (ICT) to improve the quality, performance and efficiency of urban services, including energy, utilities and transportation, so as to reduce resource consumption, waste and cost. Thus, the principal aim of a smart city is to enhance the quality of living for its people through smart technologies. But how has this idea developed and how have smart solutions in cities evolved? As previously pointed out, every year, more and more people live in cities and the numbers are increasing globally. Cities have become important centres of trade, culture, opportunity and innovation; thus, they are gaining more control over their development, both economically and politically, while evolving as complex entities with many interconnected systems. Simultaneously, technological breakthroughs have revolutionized communications, as well as the spread of information, and thus an important shift has happened that is helping cities deal with their complexities and with the pressures on their systems and that is: "a rise in data", which is now a form of capital, on the same level as financial capital in terms of generating new digital products and services. To face the challenges and threats to their existence and to become

efficiently regenerative, cities need to adopt smart solutions. They are becoming technologically empowered, as their core systems become instrumented and interconnected, enabling new levels of intelligence. It is worth pointing out that becoming a “smarter city” is a journey, not an overnight transformation. Cities must prepare for change that will be revolutionary, rather than evolutionary, as they put in place next-generation systems that work in entirely new ways (Dirks et al, 2009). In order for this change to happen, cities are being analysed from an operational point of view.

The point of departure for system analysts while examining the operational aspects of cities has been the concept of “urban metabolism”, which- as mentioned before- provides a unified or holistic viewpoint to encompass all the activities and functions of a city in a single model; and since this includes the flow of energy and resources within cities and the world beyond (Girardet, 2015), as well as the sum total of the technical and socio-economic processes that occur in cities, resulting in growth, production of energy, and elimination of waste (Stremke et al, 2014), then it could be concluded that operationally, cities are based on six core systems, each composed of different networks, infrastructures and environments related to their key functions: people, business, transport, communication, water and energy (Dirks et al, 2009); all being main constituents of the urban metabolism of cities. These systems interconnect in a synergistic manner that promotes optimum performance and efficiency and they must be considered holistically, as well as individually. The six core systems, in effect, become a “system of systems” (Dirks et al, 2009), see Figure 4. It is worth pointing out that cities face interconnected challenges, as shown in Figure 2, which shows a sample of interrelationships between core city systems, (Dirks et al, 2009), see Figure 5

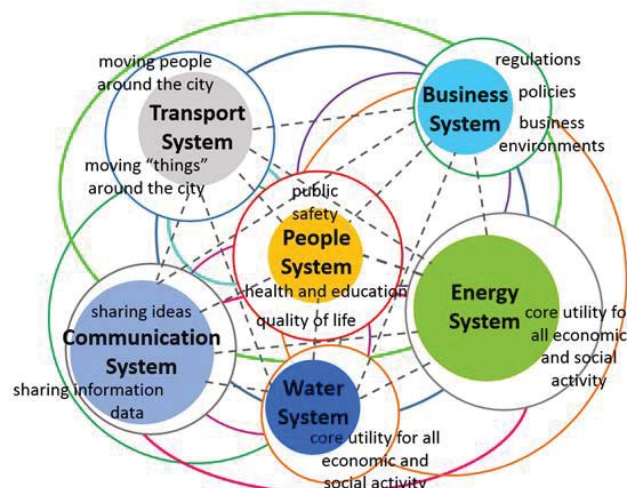


Figure 4. Synergistic interrelations and interconnections between the six core systems of a city, developed by the authors, based on the analysis made by (Dirks et al, 2009, 4-5)

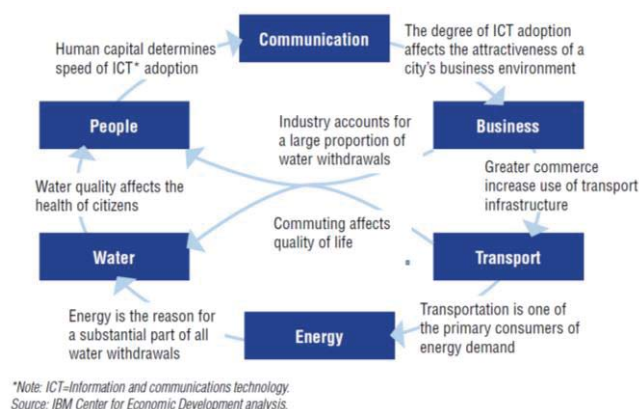


Figure 5. Sample of interrelationships between core city systems. Source: (Dirks

Based on the above concepts, the operational characteristics of smart cities have been developed, almost simultaneously with the six core systems mentioned above, taking into consideration similar kinds of synergistic interrelations, interactions and interconnections. Correspondingly, the city's people system becomes smart people; the city's business system becomes smart economy; the city's transport system and communication system are combined under smart mobility; the city's water system and energy system are combined under smart environment. Two other main characteristics are added, namely smart governance and smart living, see Figure 6, which elaborates the six characteristics of smart cities and the factors that govern them. These six characteristics and the factors have been defined by a widely-cited study on the ranking of medium sized smart cities in Europe (Giffinger et al., 2007).

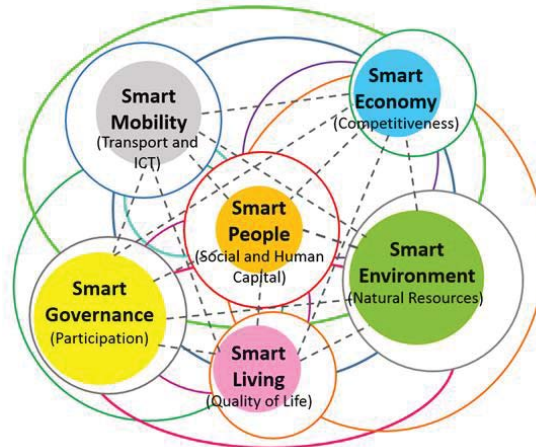


Figure 6. Synergistic interrelations and interconnections between the six operational characteristics of smart cities, developed by the authors, based on (Giffinger et al., 2007)

Every day, more technological breakthroughs are made that enhance the synergistic interrelations, interactions and interconnections between the city's complex core systems: "the system of systems", which has developed into the Internet of Things (IoT) and then the Internet of Everything (IoE). "IoT is the network of everyday physical objects, which surround us and that are increasingly being embedded with technology to enable these objects to collect and transmit data about their use and surroundings" (Vision Valley, 2017). The fine line of difference between the Internet of Everything (IoE) and the Internet of Things (IoT) lies according to Cisco, in the intelligent connection of people, process, data and things. Internet of Things (IoT) is mostly about physical objects communicating with each other, but Internet of Everything is what brings in network intelligence to bind all these concepts into a cohesive system. This is a paradigm shift that is changing lives, businesses, cities and governments, as well as creating a new era of opportunities. But what does this mean for smart cities?

According to IBM Think Academy, cities are becoming increasingly instrumented, interconnected and intelligent; the simple act of integrating sensors across city systems enables the capture of all sorts of data, which provides critical information on city activity and operations. For example, digital meters record water and energy usage in real-time; the availability of parking spaces is monitored across the city; traffic and pedestrian flow is monitored to optimize driving and walking routes; mobile and social channels enable local governments and people to communicate with each other, creating another source of useful data. Advanced analytics can now easily identify trends and patterns within these massive amounts of data. Information can be gathered and shared to facilitate understanding and interactions across the city's core systems, agencies and groups (IBM Think Academy, 2015). Thus, technological advances in smart solutions mean that cities can better understand and



control their operation and development: aspects that city managers have previously been unable to measure, and therefore unable to influence, are now being increasingly digitized. Different parts of a city's systems can be interconnected, so that information flows between them and the newly gained insights can be used for intelligent and informed decision making, using cognitive computing. These advances are making cities smarter, smarter cities- in turn- improve the efficiency of city systems both individually and collectively, and ultimately, higher efficiency levels in cities help decrease their ecological footprints.

From the above quick review of smart cities' operations, we could conclude that there are close similarities between regenerative practices and smart solutions in cities. First off, smart solutions- like regenerative practices- are circular, interconnected systems. Both use simple actions and measures that have great impacts on systems, either natural systems, in case of regenerative practices, or operational systems within a city, in case of smart solutions.

Smart solutions, like regenerative practices, are characterised by being, adaptive, systems-based, values-led, life-supporting, resilient and optimising. However, there are still some challenges and limitations in the application of smart solutions in cities. Technologically, they are still in the research and development phase and require a basic infrastructure that, in some cases, could be expensive. In addition, government policies must be supportive of integrating smart solutions across different city sectors; if this does not happen, applications will be quite difficult or might be impossible. Such policies should also empower, encourage and allow people to learn about smart solutions and use them in various life aspects.

Nevertheless, the pointed-out similarities allow for the easy integration of smart solutions with regenerative systems: an integration that could highly increase their efficiency. The following section gives examples of such integrations and how they could easily play a significant role in the efficiency of new cities.

### **Integrating Smart Solutions with Regenerative Practices in New Cities**

The context of new cities is currently undergoing a profound paradigm shift due to the rise of regenerative urban development as an organising principle, and moving from linear systems of resource use to circular systems; and also due to the breakthroughs in the world of information technology and communication.

Examples of regenerative practices in cities that integrate smart solutions include applications in traffic management, which enable car drivers to face less traffic jams, since real-time data, aligned with GIS-mapping, inform them which areas are busy. Traffic lights adjust automatically to reduce congestion. Monitoring vehicle and pedestrian levels optimize driving and walking routes. Smart parking sensors automatically alert drivers of free parking spaces (Meis, 2016); and street lights are only turned on if someone is approaching, saving large amounts of energy, which is used in other areas where they are needed: this information is known through the readings of interconnected sensors, which are linked to intelligent decision-making systems. Another application involves the use of bicycle-sharing systems, which allow people to rent or borrow bicycles for a short time, picking them up at one station and returning them to another; smartphone mapping applications show the locations of stations with available bicycles. These regenerative practices, in addition to being highly efficient and optimised due to the use of smart solutions, significantly reduce CO<sub>2</sub> emissions and thus, decrease the ecological footprint and improve air quality, resulting in positive impacts on people's health and quality of life.

Another good example, which demonstrates smart regenerative practice and circular metabolism, is that of the Eco-Industrial Park of Kalundborg, Denmark: the first full realisation



of industrial symbiosis. It shows how waste is used as a resource rather than being treated as a nuisance, which increases the resilience of the system. In Kalundborg, 20 companies and the municipality collaborate, using each other's wastes and by-products on mutual basis, within a symbiotic, circular system: efficient consumption of resources benefits the local economy, one company's waste is a cost-effective resource for another, and minimal discharges of wastes reduce environmental pollution (Girardet, 2015, 156-157).

The chain starts at the Power Station, which produces both electricity and heat for 4,500 households in Kalundborg; the station also provides steam for three companies, which have, in turn, reduced their oil consumption by 20,000 tonnes per year by using steam and have reduced their overall water consumption by 25 percent by letting water circulate between the partners. Some of the power station's cooling water is also used by a fish farm that produces 200 tonnes of trout and salmon annually, with the warm water that provides ideal growing conditions. The ash produced by the power station (80,000 tonnes) is used in the construction and cement industries. Waste heat from the power station is used for district heating and greenhouses. Treated sludge from the pharmaceutical plant is used in neighbouring farms. The companies and the municipality have a joint waste-water treatment facility, with only minimal discharges into the Baltic Sea. Newspaper, cardboard, rubble, iron, glass, green waste and kitchen wastes are all recycled and turned into new products (Girardet, 2015, 156-157), see Figure 7.

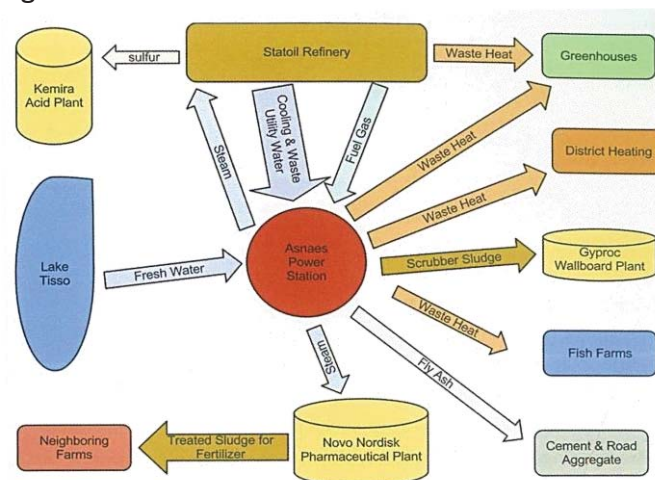


Figure 7. Diagram illustrating Kalundborg as a prime example of "industrial ecology". Source: (Girardet, 2015, 157)

As a model, Kalundborg was the first example of separate, unrelated industries that collaborated to gain competitive advantage by energy exchange, material exchange, information exchange, and/or product exchange. It is precisely the diversity of needs and uses of resources that makes the exchanges valuable. If all stakeholders had the same type of production, they would not have been able to use each other's residuals. This symbiosis came about through voluntary action, where the presence of each of the industries increases the viability of the others and where resource savings and environmental protection are considered. Not only is it a sustainable process, but also a regenerative one, where different environments are enhanced and restored; where strategies are comprehensive through the adoption of holistic approaches; where systems are circular; where human development, as well as socio-cultural and political frameworks are considered and integrated as inherent parts of a whole ecosystem; where waste is treated as an opportunity; where the resilience of the system is enhanced; where efficiency is improved and last but not least, where

achieving maximum benefits is reached through using local resources and relying on close hinterlands. This concept could be used in new cities, making even more system enhancements through the reliance on renewable energy sources and using smart technological applications by instrumenting the whole system, where interconnected sensors capture all parameters and values across the system, and are governed by intelligent, decision-making cognitive computing systems that control the actuators, which- in turn- optimise the overall system accuracy and efficiency.

Another important application is that of smart grids. As defined by the American Federal Energy Regulatory Commission, a smart grid is an electrical grid, which includes a variety of operational and energy measures including smart meters, smart appliances, renewable energy resources, and energy efficient resources (Kathan et al., 2008). The important aspect of the smart grid is that it controls and improves the efficiency of electrical power generation, distribution and consumption, with load adjustments and balancing. It is environmental-friendly since it enables a larger penetration of renewable energy sources and energy storage capacities; it is based on reliable and flexible network technologies, which operate resiliently against any kinds of attacks or natural disasters. This means that energy is used exactly where it is needed, which- in turn- most importantly decreases CO<sub>2</sub> emissions, and thus the ecological footprint.

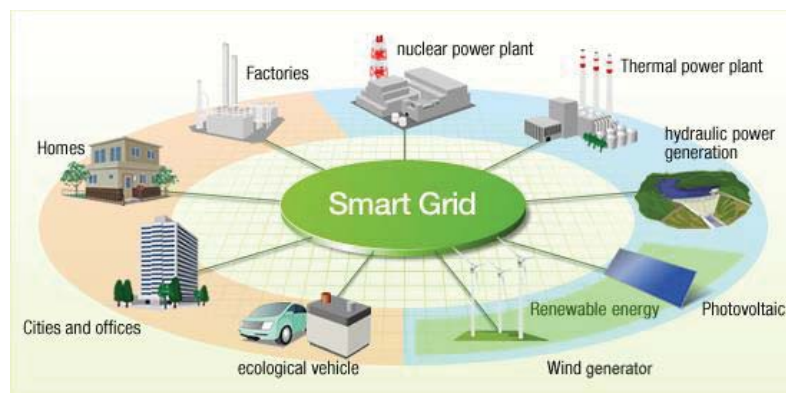


Figure 8. A diagram explaining the concept of the smart grid, showing power generators on one side and power consumers on the other.

Source: (Urbana World, 2016).

Copenhagen is already a frontrunner in terms of integrated energy systems and to meet its target of becoming carbon neutral by 2025, the city is working on the development of integrated and smart electricity and energy systems through the cooperation with other municipalities and companies on both the national and international level (Girardet, 2015), another way of demonstrating global regenerative practices.

Generally speaking, Copenhagen is a very good example of applying smart, regenerative practices; it has taken numerous measures to become more liveable, including the use of electric vehicles, integrated transport systems, cycling solutions, and green transport, all while applying smart solutions that increase the efficiency of mobility within the city, again, to reach its target of becoming carbon neutral by 2025. This target is also achieved through the establishment of a smart interconnected system of wind farms inside and around the city to generate clean energy and is being achieved via cooperative ownership, thus, simultaneously creating community-owned facilities, involving the public and utilising local skills. Copenhagen is also a world leader in district heating, where the system is more optimised by using smart technologies and shifting to renewable energy. Facilities use surplus energy from district heating networks to provide cooling for larger businesses. The city is also

looking for cost-effective ways to demonstrate new, green architecture, being conscious about energy consumption when buildings are constructed or renovated: there are huge savings made from smart energy optimisation in buildings, recovering investments really quickly (Girardet, 2015). The above examples serve to show how smart solutions and regenerative practices could be easily integrated in new cities in the early planning stages.

## **Conclusion**

Regenerative practices and smart solutions in cities have similar attributes: they are both optimising, adaptive, systems-based, values-led, life supporting and resilient. They demonstrate these characteristics in their related fields within the city's interconnected systems: regenerative practices demonstrate them through circular urban metabolisms, while smart solutions demonstrate them through operations. The examples shown in the previous section, show that when both are integrated, regenerative urban development practices are especially enhanced through smart solutions. They become optimising not only through balancing scope and scale, but also through sensitively adjusting the system's performance to meet set targets, which increases the efficiency and effectiveness of the system. They become more adaptive to change, by being very sensitive and highly responsive through advanced analytics. Regenerative urban development practices are systems-based, but this is more enhanced through the strong instrumentation, interconnectivity and intelligence of smart network systems. They are values-led, but smart systems help with quantifying all the different aspects involved in regenerative practices, through cognitive computing, which is continuously learning how best to gain insights, relate occurrences and respond in real-time and with high accuracy. Regenerative urban development is life-supporting by working with the grain of nature and ensuring that biodiversity considerations are embedded in all the main sectors of economic activity, and smart solutions take these practices on step further by creating systems that support and maintain the natural environment. Regenerative practices are resilient by regarding disturbances as opportunities and are strongly supported in this regard through smart solutions that can easily perform under extreme conditions- see Figure 9. The examples also show that the integration of smart solutions with regenerative urban development practices increases their efficiency, accuracy and optimisation, such as in the case of traffic management systems, green transport, controlling power generation, distribution and consumption, as well as allowing energy to be used exactly where it is needed, and using more and more renewable energy sources, which are instrumented, interconnected and intelligent through the use of smart network systems; in addition to creating a global network of environmental data collection, through the simple use of sensors, to help cities figure out the best ways to quickly cut emissions. In addition, smart solutions are also devised to make the use of local materials and the reliance on close hinterlands more efficient and enhanced.

However, as previously mentioned, there are still some challenges and limitations in the application of smart solutions in cities, as they are still in the research and development phase and require a basic infrastructure that could be expensive. In addition, government policies must be supportive of integrating smart solutions across different city sectors.

Nevertheless, smart solutions are main actors in regenerative urbanism and when they are integrated with regenerative urban development practices, both the resilience and the circular urban metabolism of the city are enhanced; in addition, the efficiency of the interconnected systems increases, and accordingly, the ecological footprint of the city decreases.

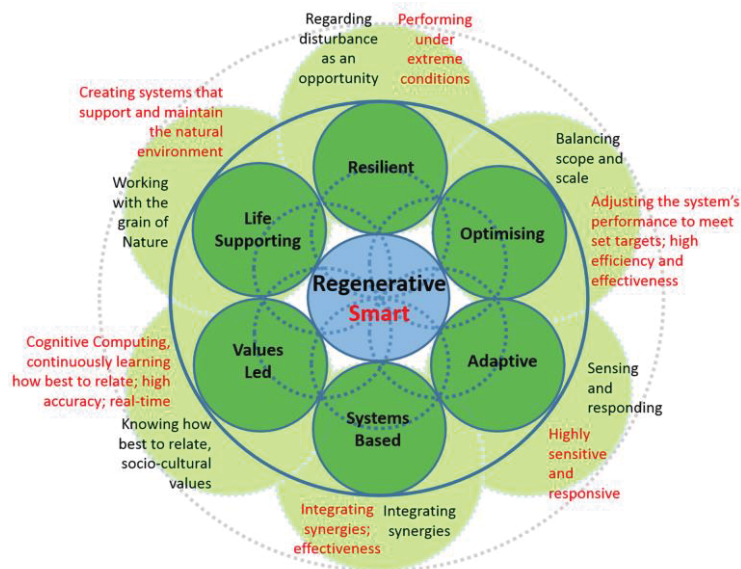


Figure 9. A diagram showing how regenerative systems benefit from the integration of smart solutions

## References

- Carri, (2013). *Definitions of Community Resilience: An Analysis*. Community and Regional Resilience Institute.
- Dirks, S. and Keeling, M. (2009). *A vision of smarter cities, how cities can lead the way into a prosperous and sustainable future*. IBM Global Business Services, IBM Institute for Business Value.
- Giffinger, R. et al., (2007). *Smart cities – Ranking of European medium-sized cities – Final Report*. Centre of Regional Science (SRF), Vienna University of Technology (VUT) - Department of Geography, University of Ljubljana - Research Institute for Housing, Urban and Mobility Studies (OTB), Delft University of Technology. [http://www.smart-cities.eu/download/smart\\_cities\\_final\\_report.pdf](http://www.smart-cities.eu/download/smart_cities_final_report.pdf)
- Girardet, H. (2015). *Creating Regenerative Cities*. Abingdon, Oxon and New York, NY: Routledge.
- Girardet, H. (2008). *Cities People Planet: Urban Development and Climate Change*. Second Edition, London: Wiley.
- HCU, HafenCity University (2010). *Regenerative Cities*. Hamburg.
- IBM Think Academy, 2015. *How It Works: Smarter Cities*. YouTube channel.
- Kathan et al. (2008). *Assessment of Demand Response and Advanced Metering - Staff Report*. Federal Energy Regulatory Commission.
- Lipper, B. (2016). *How to Develop a Resilience Strategy*. <http://www.100resilientcities.org/how-to-develop-a-resilience-strategy/>, consulted 30/09/2017.
- Mahmoud, R. (2017). *New Cairo's Urban Dynamics: Redefining Gentrification as a Main Actor of Social Resilience*. In: *Procedia Environmental Sciences* 37 (2017) 429 – 441, p-p 429-441.
- Meis, K. (2016). *3 ways IoT is already making cities smarter*. <http://www.greenbiz.com/article/3-ways-iot-already-making-cities-smarter>
- RGDU (2017). *Smart Cities and Urban Metabolism*. Research Group of the Department of Urbanism-Delft University of Technology, in: <https://urbanmetabolism.weblog.tudelft.nl>
- Stremke, and Voskamp, I (2014). *The Pulse of the City: Exploring Urban Metabolism in Amsterdam*. P.3. <http://www.ams-institute.org/wordpress/wp-content/uploads/2015/05/2014-The-Pulse-of-the-City-VOSKAMP-and-STREMKE.pdf>
- UNISDR (2017). *Making Cities Resilient*. At: <http://www.unisdr.org> consulted 30/09/2017
- Urbana World, (2016). *IEEE SMART GRID and THINK SMARTGRIDS collaborate to launch first IEEE International Forum on Smart Grids for Smart Cities*. <https://www.urbanaworld.com/ieee-smart-grid-and-think-smartgrids-collaborate-to-launch-first-ieee-international-forum-on-smart-grids-for-smart-cities/>
- Vision Valley Report, (2017). *IoT Revolution Unlocking a New World of Opportunities*.
- Zarrilli, D. (2017). *New York City: A Living Laboratory for Urban Resilience*. In: <http://www.100resilientcities.org/> consulted 30/09/2017

# REDUCING THE EXPOSURE TO GASOLINE IN EGYPTIAN NEW SETTLEMENTS: A PUBLIC HEALTH CONCERN

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**Abstract:** With the evolution of ecological awareness concerning the relationship between urban development and the environment, attitudes are being rethought, environmental problems started to motivate the emergence of a new ecological vision of society. Although, gasoline stations became an integral part of our daily lives, they are usually associated with environmental and health risks and considered a source of pollution that have a significant effect on the surrounding communities. In Egypt, like in other countries, it is relatively common to come across gasoline stations surrounded by houses, particularly in urban areas and in spite of the serious efforts to reduce air pollution; it remains a major health risk. As the contamination risk related to hydrocarbons from these stations is very severe, the research focuses on air pollution problems associated with gasoline stations along with the subsequent impacts on human health, environment and the nearby houses. The problem is that there are still no restrictions in the Egyptian local regulations and legislation concerning site selection of these stations. That's why a question was raised about what should be done to minimize potential adverse impacts of such stations. The aim of the research is developing guidelines for gasoline stations in New Sustainable Settlements in Egypt to reduce their risks and negative impacts. The research was based on inductive approach through identifying sources of air pollutants, health risks and limit values of these pollutants and the international limit values for the distance between these stations and the nearby residents. In addition to a practical study that investigates the impact of emissions of pollutants from gasoline stations on the local air pollution. As a result, guidelines are developed to provide designers and planners with suggested procedures, requirements and safety design measures for the mitigation of the effect of toxic fumes emanating from gasoline stations.

**Keywords:** Health and safety requirements, Air pollution, Gasoline stations, Volatile Organic Compounds, Reduction of air pollution in new settlements

## Introduction

Living near gasoline stations may increase exposure to benzene. In recent decades, the global concern about the degradation of air quality has been increasing and many studies have shown the impacts of these stations on the environment and human health in addition to the potential health risks that may exist for people living in proximity to these stations.

While there is a limited scientific basis with which to determine an appropriate minimal setback for gasoline stations away from residents living near these facilities, there is real potential for human exposure to hazardous air pollutants and the minimum setback needs to be addressed for the health and safety of the residents.

## The Problem of the research

The most serious impact of gasoline stations is the additional risk to public health. As the potential contamination risk related to air pollutants especially hydrocarbons from gas stations could be very severe, which could lead to the degradation of health quality for people who live and work in the neighborhood, the issue of gasoline vapor dispersion should be highly concerned (World Health Organization, 2010). That's why this research focuses on the air pollution risks related to the gasoline stations and what should be done to minimize potential adverse impacts of such stations in New Egyptian Settlements.



### ***What makes the situation worse in Egypt?***

Although most of gasoline stations in Egypt are commonly located in residential and commercial areas close to homes, schools, playgrounds, etc. (Correa et al, 2012), there is currently nothing in building codes or any local jurisdiction that require spacing between gasoline stations and residential areas, in addition, the city council has no authority over the site plan of these stations and the private sector can establish any station in privately owned land if it is fulfilling the requirements of Petrol Stations Directory developed by the Ministry of Petroleum that doesn't give any concern to air pollution or the human health.

Moreover, according to the ENVIRONMENTAL IMPACT ASSESSMENT GUIDELINES FOR OIL AND GAS SECTOR developed by Egyptian Environmental Affairs Agency (EEAA) of the Ministry of State for Environmental Affairs in October 2001, Petrol Stations (gasoline, natural gas and solar) in environmentally sensitive areas as residential are classified as B - Category projects which means that the developer requests an Environmental Screening Form (B) from EGPC, Governorate or EEAA to fill it out and not classified as C-category projects that require a full EIA (EEAA, 2001).

As the higher the ambient temperature, the higher the rate of evaporation becomes, this makes the issue more pressing in Egypt where summer temperatures can reach 45 degrees Celsius in the sun. In addition, the technology to minimize toxic fumes from escaping into the atmosphere which is wide spreading in Europe is still not applicable in Egypt and the Environmental law does not enforce any requirements on Gasoline Stations. That's why we are in need for guidelines for Gasoline stations in new settlements in Egypt.

### **The aim of the research**

The aim of the research is to improve the overall quality of life for residents in the Egyptian New Settlements and to protect health and the environment against any kind of air contamination. In addition to developing guidelines for protecting public health from adverse effects of air pollutants resulting from gas stations that are known or likely to be hazardous to human health or wellbeing, and to eliminate or reduce to a minimum exposure to those pollutants that are known or are likely to be hazardous in New Sustainable Settlements in Egypt, and to guide national and local authorities in their risk management decisions.

### **Methodology**

Gasoline stations raise a number of concerns about public health risks. To understand this, a variety of factors should be considered, how a gasoline station can affect the quality of air and the human health, the concerns that these trends have raised and the factors that contribute to or influence such impacts. Then the research illustrates international practices and appropriate ways of air pollution prevention that could be applied in the New Settlements. As part of this Research and based on a field assessment, 6 different gasoline stations were examined to discover the actual situation in Egypt. After identifying the problem, mitigation strategies should be developed and implemented and necessary procedures and practical steps should be taken to minimize air pollution and risks to public health.

## Process description

This research concerns retail gasoline stations where gasoline (petrol) and other automotive fuels such as diesel, biofuels and liquefied petroleum gas (LPG) are sold. Such facilities may range in size and may also include automobile repair services and other services. The typical layout of a fuel station would include (EBRD, 2009):

- Underground Storage Tanks (USTs) and sometimes Aboveground Storage Tanks (ASTs).
- Pump island where one or more fuel dispensers are located.
- Enclosed office for a cashier.
- Concrete hard standing area surrounding the pumps.

Fuel is delivered from bulk storage depots by road tanker and unloaded into the storage tanks at the fuel station by the tanker driver. Fuel is piped from the storage tanks to the dispensing pumps. In Egypt, as in many other countries, automotive fuels are dispensed by a trained operator employed by the facility. However, the trend in developed countries is towards self-service customer operation.

## Sources of Gasoline Vapor Dispersion in Gasoline Stations

Air Pollutants released at gasoline stations are mainly due to the following process shown in Table 1:

Table 1. Sources of Air Pollution at Gasoline Stations

Sources of Air Pollution at Gasoline Stations
Gas Station Normal Operation (emission of vaporized gasoline) (AQMD, 2007)
<ul style="list-style-type: none"><li>• Loading: Loading emissions occur when a cargo tank truck unloads gasoline to the storage tanks at the gasoline station. Storage tank vapors are emitted from the vent pipe during the initial fuel transfer period. These emissions are significantly reduced when the vent pipe includes a pressure/vacuum valve.</li><li>• Breathing: Emissions occur through the storage tank vent pipe as a result of temperature and pressure changes in the tank vapor space.</li><li>• Refueling: Emissions occur during motor vehicle refueling when gasoline vapors escape through the vehicle/nozzle interface.</li><li>• Spillage: Emissions occur from evaporating gasoline that spills during vehicle refueling (CAPCOA, 1997).</li></ul>
Accidental Leakage or Spills
<ul style="list-style-type: none"><li>• Leaks from storage tanks and connecting pipework arising from damage, aging or improper installation.</li><li>• Small spills during unloading (fuel delivery) or vehicle filling (vehicle filling) which are not cleaned up.</li><li>• A major spill, such as a tank failure or overfilling (EBRD, 2009).</li></ul>
Tailpipe emissions (exhaust emissions coming from the tail pipes of the cars to be fueled)
Some of the most problematic components of tailpipe emissions are those created by the incomplete combustion of gasoline and incomplete combustion is most severe when cars are moving slowly - because automobile engines are least efficient at burning gasoline when the cars are moving slowly (i.e. at/near idling speeds) (Australian Capital Territory, 2014).

### ***Factors increasing emission of toxic air pollutants in gas stations***

**Aging:** Over the lifespan of a gasoline station, concrete pads underneath the pumps can accumulate significant amounts of gasoline, which can eventually penetrate the concrete and vaporizes into the air (U.S. Department of Health and Human Service, 2007).

**Traffic congestion:** Mega Gasoline stations attract large numbers of customers. In the most general sense, having lots of cars coming to a site (to buy gasoline) generates traffic. The situation in which the mega gasoline station - by virtue of its specifics (location, mode of operation) - causes the kind of traffic congestion that leads to slow moving (or idling) cars and thus increases the extent to which the cars visiting the site emit the components of incomplete combustion.

### ***The damage caused by the released emissions depends on:***

- The amount of material released.
- The proximity of the facility to sensitive environmental receptors.
- The local geology (i.e. how easily the leak can pass through the underlying soil).

### **Health Risks and Limit Values for Air Pollutants from Gasoline Stations**

Typically, gasoline contains more than 150 chemicals including small amounts of benzene, toluene and xylene. How the gasoline is made determines which chemicals are present in the gasoline mixture and how much of each is present. The actual composition varies with the source of the crude petroleum, the manufacturer, and the time of year. Table 2 shows the health risks and limit values for air pollutants from gasoline stations identified by the World Health Organization (WHO) (World Health Organization, 2000) and the National Institute for Occupational Safety and Health (NIOSH) (National Institute for Occupational Safety and Health, 2007).

Among the BTEX compounds, benzene is considered the most hazardous component of hydrocarbon and has been classified as a Group 1 carcinogenic substance by the International Agency for Research on Cancer and the US Environmental Protection Agency (EPA) (Smith, 2010). The WHO estimated that benzene concentration of  $1.7 \mu\text{g}\cdot\text{m}^{-3}$  can cause leukemia in 10 cases per 1 million people (Cruz et al, 2017).

Burning gasoline also produces carbon dioxide, a greenhouse gas. And if the station is also a repair shop, mechanics use solvents, antifreeze and lead products, and may work on vehicles that have asbestos in brakes or clutches. Auto refinishers and paint shops use even more potentially harmful chemicals.

Ground-level ozone caused by a mixture of volatile organic compounds, some of which are found in gasoline vapors, and others, like carbon monoxide, that come from car exhaust. Breathing ozone can trigger a variety of health problems, particularly for children, the elderly, and people of all ages who have lung diseases such as asthma. Ground level ozone can also have harmful effects on sensitive vegetation and crops.

There is no value set for acceptable levels of BTEX in ambient air in the Egyptian law. For comparison, the U.S. standards of the National Institute for Occupational Safety and Health (NIOSH) are used as shown on Table 2 (Correa et al, 2012).

Table 2. Health Risks and Limit Values for Air Pollutants from Gasoline Stations

Adverse Effects of VOC's (BTEX) in Gasoline vapor to Human Health (National Institute for Occupational Safety and Health, 2007)			Occupational exposure limits for BTEX – 8 hours	
Compound	Acute Exposure Effects	Chronic Exposure Effects	NIOSH (µgm/m3)	Hazard Degree
Benzene	Headache, dizziness, drowsiness, confusion, tremors and loss of consciousness	Leukemia	3.19	Maximum
Toluene	Chemical pneumonia, respiratory failure	Embryonic lesion, liver and kidney failure	375	Average
Ethyl benzene	Sister chromatid exchange, testicular degeneration	Lung and central nervous lesion,	435	Average
Xylene	Dizziness, shiver, dyspnea	Embryo toxicity, dermatitis	435	Average
Effects of TVOC on Human Health			Occupational exposure limits for TVOC	
TVOC	Eye irritation / watering, nose irritation, throat irritation, headaches, nausea / vomiting, dizziness, asthma exacerbation	Cancer, liver damage, kidney damage, central nervous system damage	TVOC concentrations in non-industrial environments should be below 25 µgm/m3 (Environment Institute, 1997) (US EPA, 2017)	
Effects of NOx on Human Health (National Institute for Occupational Safety and Health, 2007)			Maximum (µgm/m3)	Exposure time
NOx (No2)	Causes significant inflammation of the airway		200	One Hour
			40	One year
Effects of fine particulates (e.g. PM 2.5) on Human Health (National Institute for Occupational Safety and Health, 2007)			Maximum (µgm/m3)	Exposure time
Fine particulates (e.g. PM 2.5)	Respiratory problems including mortality and risks for bronchitis		25	24 hours
			10	One year
Effects of Ozone pollution on Human Health (National Institute for Occupational Safety and Health, 2007)			Maximum (µgm/m3)	Exposure time
Ground-Ozone	Higher ozone levels can lead to respiratory problems and asthma		200	One Hour
			120	8 hours

### **Health Hazard for People Living near Gas Stations from International Studies**

Gas stations can pose significant hazards to neighbors, especially children. Repeated high exposure to gasoline, whether in liquid or vapor form, can cause lung, brain and kidney damage, according to the NIH's National Library of Medicine.

A link between childhood leukemia and residence within 100 meters of a gas station (Benzene) was shown in a French study published in the Occupational and Environmental

Medicine journal (Steffen et al, 2004). The more the children are exposed to benzene (found in gasoline) the higher their risk becomes in developing this form of cancer. The research found that children who live next to a petrol station are four times more likely to develop acute leukemia than other children in the same area. The majority of children stricken by cancer were aged 2 to 6.

***Factors affecting severity of health effects:***

If you are exposed to a hazardous chemical such as gasoline, several factors will determine whether harmful health effects will occur and what the type and severity of those health effects will be. These factors include (U.S. Department of Health and Human Service, 2007):

- The effective dosage.
- Distance from the source.
- Duration of exposure as acute or chronic effects.
- The other chemicals to which being exposed.
- Individual characteristics such as age, sex, family traits and state of health.

**International Limit values for the distance between Gas stations and the nearby residents**

There are a limited number of scientific studies that has tried to investigate the appropriate minimal setback for gasoline stations away from residents living near these facilities. Table 3 shows some International Limit values for the distance between Gas stations and the nearby residents whether these limits are determined by the city council or from international studies to be used as a reference in the determination of the distance that should be applied in the Egyptian New Settlements.

Table 3. International Limit values for the distance between Gas stations and the nearby residents

Cities where zoning-mandated spacing exists to protect homeowners from the negative health effects of gas stations (No gasoline station can be built without city-level approval and they must be equipped by recovery systems)	
City, State, Country	Minimum Distance between Gasoline Stations and residents
Milford, CT, USA	90 meters
Raleigh, NC, USA	122 meters
Chicago, IL, USA	46 meters
International studies to determine the minimal setback for gasoline stations away from residents living near these facilities	
City, Country	Minimum Distance between Gasoline Stations and residents
Murcia, Spain (Morales, 2010)	75 meters
Rio de Janeiro, Brazil (Correa, 2012)	150 meters

***The distance from a gas station at which benzene levels equals urban background levels depends on several factors including:***

- Number of petrol pumps and the amount of fuel drawn from them.
- Vapor recovery methods used.
- The volume of gas pumped from a station.
- Spills during fueling.



- The structure of the surroundings, the meteorological conditions and the weather conditions.
- Traffic intensity.

### **The Practical Study**

Exposure to Volatile Organic Compounds (VOCs) can cause a variety of adverse health effects. In urban areas, gasoline stations are considered the second main source of VOCs after traffic (Morales et al, 2010). That's why the practical study focused on investigating the level of emissions of the Total Volatile Organic Compounds (TVOCs) from gasoline stations in local urban areas to be used as a guide in developing guidelines for the New Settlements in Egypt.

Previous investigations on air quality (AQ) in developed countries cannot be applied in a developing one such as Egypt, due to the difference in climatic conditions, urban boundaries, housing layouts, way of life and socio-economic conditions. This study is to examine the emissions of total volatile organic compounds (TVOC) and Carbon Monoxide (CO) from gasoline stations within developed urban like Giza city in Egypt and the effect of these stations on the surrounding air and on the adjacent and / or attached residential buildings.

Six gasoline stations were selected in Giza city which is characterized by tropical climate with uniformly high temperature all the year round, high humidity, dusty weather and monthly mean temperatures varying between 38 °C (June/July) and 15 °C (January/February) and situated at latitude of 30°00 Deg. North, and longitude of 30°01 Deg. East. Outdoor air Sampling was carried out during August month.

An outdoor air quality study was conducted on variable floor levels in attached residential buildings to the gasoline station for 6-stations near streets. These floor levels are the ground, second, fourth and sixth floor. These sampling sites comprised four outdoor levels along the vertical direction of each building representing levels +1.00m, +6.00m, +11.00m and +16.00m. Measurements were made in a continuous manner during August month for 24-hours during working hours and weekends. Outdoor samples were collected for total volatile organic compounds (TVOC), Carbon monoxide (CO), Dry-Bulb temperature (DBT), and relative Humidity (RH%).

### **Measuring Strategy**

Measurements were carried out with the aid of two state-of-the-art instrumentations, Figure 1 shows Aeroqual's Series 500, Portable Air Quality Monitor that was equipped with 3-air sampling probes for TVOC and CO, it was used to measure the readings limits for mentioned parameters for the validation processes. In addition to calibrate the custom made station including data acquisition system. Such station was designed to operate for 3-months continuously and could measure all parameters at the same time as shown in Figures 2- 4.

All transducers were connected with National Instruments, NI, USA made of 12-bit data logger as indicated in Figures 5 and 6 which is serially connected to personal computer as shown in Figure 7. The computer was loaded with custom made NI, Lab-View software as shown in Figures 8 and 9. Lab-View software was the way to collect all gathered environmental data at 100 samples per second with suitable data-transfer speed and accuracy.



Figure1. Aeroqual's Portable Air Quality Monitors



Figure 2. Sauter, RH% & DBT Transducer



Figure 3. Greystone CO Sensor & Transducer



Figure 4. Siemens VOC & CO2 Sensor & Transducer



Figure 5. Bus-Powered Multifunction DAQ USB

- NI USB-6008 is a simple and low-cost multifunction I/O device from National Instruments.
- The device has the following specifications:
  - 8 analog inputs (12-bit, 10 kS/s)
  - 2 analog outputs (12-bit, 150 S/s)
  - 12 digital I/O
  - USB connection, No extra power-supply needed
  - Compatible with LabVIEW, LabWindows/CVI, and Measurement Studio for Visual Studio .NET
  - NI-DAQmx driver software
- The NI USB-6008 is well suited for education purposes due to its small size and easy USB connection.




Figure 6. 12-Bit Device, NI USB-6008

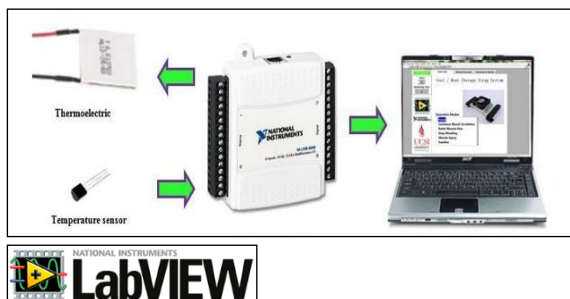


Figure 7. Used Data Acquisition Software

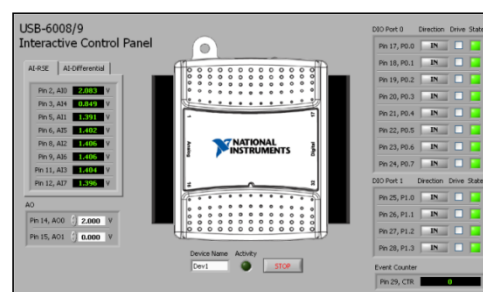


Figure 8. LabView Front Panel on Personal Computer

### Discussion of the practical study

Figures 9 - 20 show six gasoline stations in Giza, these stations are in zone of 2.50 km by 2.50 km to serve different life style levels. Figures 9- 11 show the biggest station in Giza that is equipped with Gasoline, Diesel, and Natural Gas pumps and faces the Nile River and opened square (ST-01). Figures 12 and 13 show another similar in size station but located within the main road and branched streets in addition to the presence of elevated bridge over the main road (ST-02). Figures 14, 15, 19 and 20 show two small gasoline stations facing the Nile River from the main facades (ST-03) and (ST-04). Figures 16- 18 show another Gasoline stations 1.00 km far from the Nile River Road and surrounded from 3-sides by residential building and the main façade facing main street, ST-05 & ST-06. It is worth to mention that gained measured parameters show a huge amount of data that could not be presented within this study but it is averaged, summarized and presented in Table 4.



Figure 9. Corner Type Station Front View, ST-01



Figure 10. Corner Type Station Side View, ST-01



Figure 11. Near View of Corner Type Station, ST-01



Figure 12. End Street Type Station, Gasoline Pumps, ST-02



Figure 13. End Street Type Station, NG Pumps, ST-02



Figure 14. Nile View Type Station, ST-03



Figure 15. Nile View Type Station, ST-03

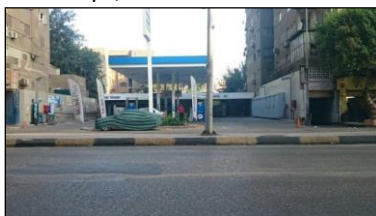


Figure 16. East-West Street In-Line Type Station, ST-05



Figure 17. North-South Street In-Line Type Station, ST-06



Figure 18. North-South Street In-Line Type Station, ST-06



Figure 19. Nile View Type Second Station, ST-04



Figure 20. Nile View Type Second Station, ST-04

Table 4 shows the concentrations of Total Volatile Organic Compounds (TVOC) and Carbon Monoxide (CO) in each of the selected gas stations. A detailed measurement of TVOC and discussion for ST-02 is presented below for typical week in August in Figures 21- 24. The outdoor level of total volatile organic compounds (TVOC) was especially high in the ground level due to the effect of traffic emissions.

Table 4. The concentrations of measured Total Volatile Organic Compounds (TVOC) and Carbon Monoxide (CO)

Measured values in August	Station					
	ST-01	ST-02	ST-03	ST-04	ST-05	ST-06
TVOC ( $\mu\text{g}/\text{m}^3$ )	15.50-45.85	30.00-500.00	40 - 227.00	35 - 245.50	40.21 - 60.58	45.11-80.00
CO (PPM)	15.50 - 22.75	25.00 - 35.25	20.75 - 37.15	20.15 - 37.00	30.55 - 44.68	28.88 - 43.00
Averaged Weather Condition (DBT/RH%)	39.57 Deg.C / 40% RH	38.00 Deg.C / 42% RH	39.00 Deg.C / 44% RH	38.85 Deg.C / 42% RH	38.95 Deg.C / 45% RH	39.25 Deg.C / 43% RH

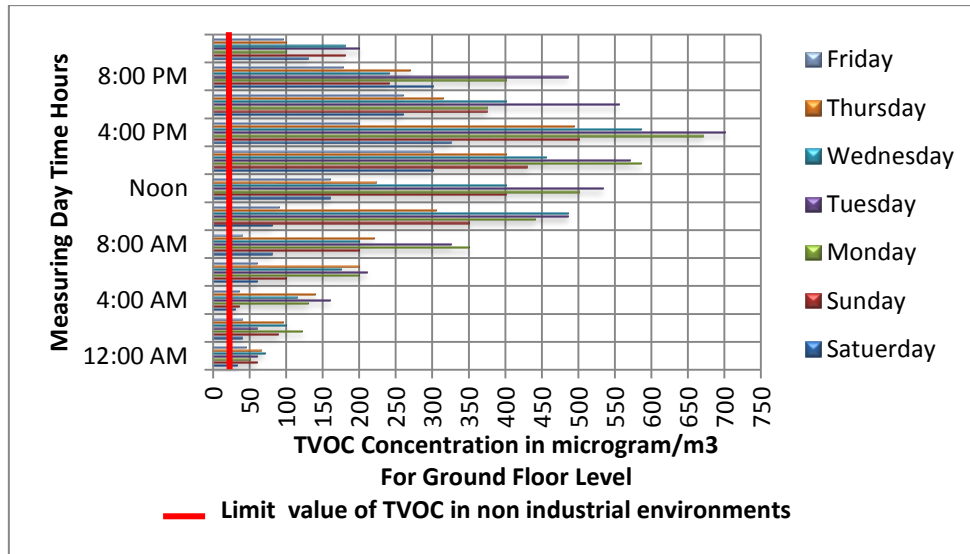


Figure 21. Measured TVOC for Station ST-02 Measured at Ground Floor Level

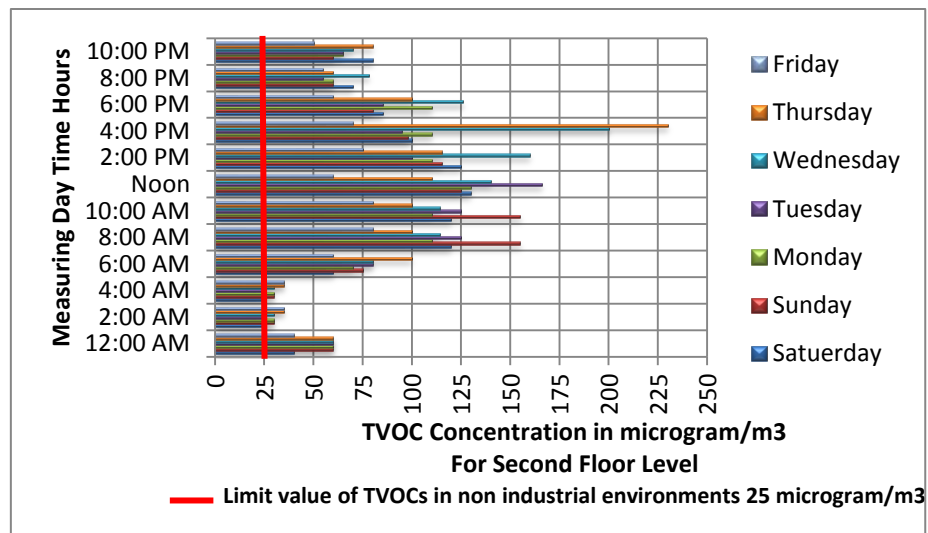


Figure 22. Measured TVOC for Station ST-02 Measured at Second Floor Level

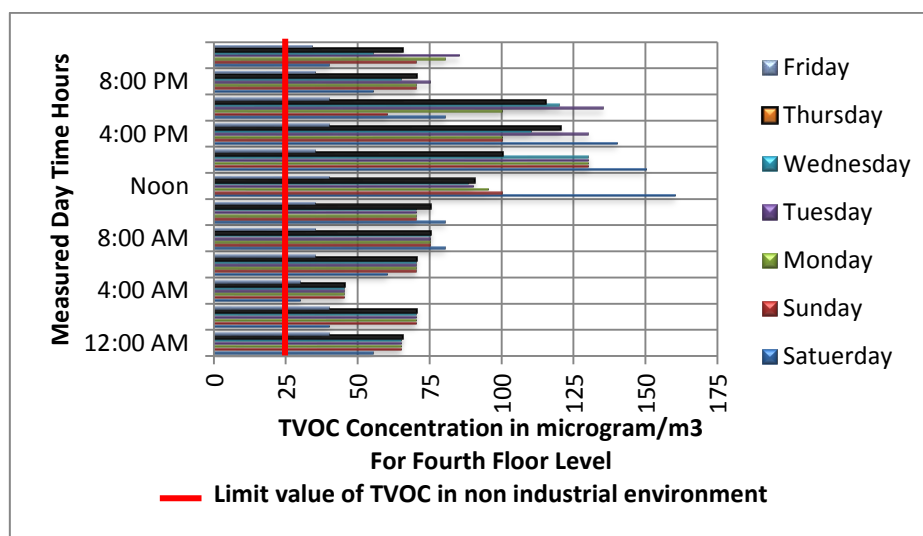


Figure 23. Measured TVOC for Station ST-02 Measured at Fourth Floor Level



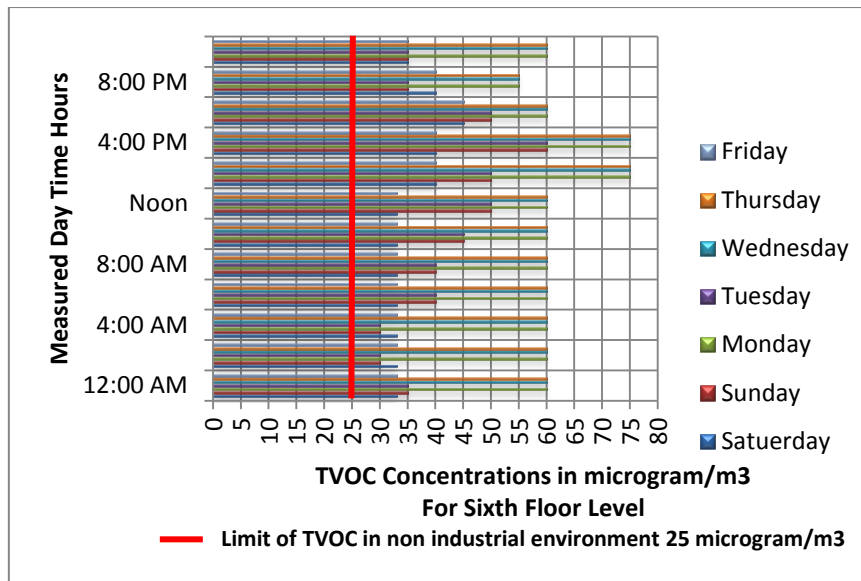


Figure 24 Measured TVOC for Station ST-02 Measured at Sixth Floor Level

Measurements in vertical direction for TVOC and CO from gasoline stations and their influence on the adjacent or attached residential buildings are subjected to sensible variations and in some cases the readings are deviated. This is due to the effect of streets and traffic emissions, for that reason the measuring strategy for this study was based on the continuous data logging during the month, additional measurements with estimation of the emissions weighted-average "on the around streets" were carried out on street levels to evaluate the impacts of these factors on the measured data. Such estimation led to the following simplifications as shown in Table 5:

Table 5. The percentage of the traffic emission from the total measured TVOCs and CO

Time	Weekends (Fridays and Saturdays)		Normal Working Days	
	TVOC	CO	TVOC	CO
11:00 PM to 05:00 AM	37%	20%	35%	20%
05:00 AM to 10:00 AM	42%	33%	45%	30%
10:00 AM to 04:00 PM	58%	50%	70%	55%
04:00 PM to 11:00 AM	50%	30%	63%	50%

### Results of the Practical Study

- The concentration levels of TVOC meets the international limits stated by EPA (25  $\mu\text{g}/\text{m}^3$ ) within 80% of the day time with exposure time more than 20-Hrs/Day, while during the remaining 20% of day time the TVOC are offset over EPA limits by 30% with exposure time about 4-Hrs/Day when the majority of occupants aren't in their residential units.
- The effect of high-rise building and the extra elevated bridges are making semi-enclosed compartmental that prevent the scavenging wind effects and minimizing any gust speed which lead to a significant increase in air pollution levels.
- It is recommended that in the new constructions within crowded urban in the lower levels,"e.g. Ground, first & second floors" could be occupied by commercial applications



that utilize mechanical ventilation and air conditioning to filter any polluted air from outside.

- Detailed measurements for the individual components of TVOCs should be considered in the future studies.
- The more contaminated the zone surrounding the gasoline station because of other sources (traffic), the lower the impact of pollutants at the service station. If traffic in the area surrounding the petrol station is very intense, and exceeds the emissions from the station itself, pollution at the service station is overlapped and goes unnoticed over short distances.
- There is not much use in protecting people from petrol stations if other sources of air pollution as traffic are not controlled or reduced.
- These results indicated that more attention should be given for site selection of gasoline stations.

## Results

From all the previous study, guidelines are developed for the sake of better future in the New Egyptian Settlements.

### ***Guidelines to minimize exposure to air pollutants from gasoline stations in New Egyptian Settlements***

- Government agencies should consider establishing rules and permitting and enforcement procedures to reduce pollution from gasoline stations for the sake of environmental health justice and protection. The existing laws and regulations should be improved. Egyptian Environmental Affairs Agency (EEAA) of the Ministry of State for Environmental Affairs should direct all the oil companies to ensure installation of vapor recovery systems at petrol pumps all around the country.
- Modification of the building code: There is a great need to modify the code to overcome the drawbacks of living near gas stations.
  - The establishment of zoning code by local authorities that should state the spacing between a gas station and housing or other facilities by a belt of a minimum distance of:
    - 50 meters should therefore be maintained between petrol stations and housing.
    - 100 meters for especially vulnerable facilities such as hospitals, health centers, schools and old people's homes.
  - A three meters landscape 'buffer strip' from desert trees along the boundary must be maintained.
  - Gas stations should be placed on the south side of residential areas.
- Environmental Impact Assessment (EIA): Gasoline stations should be classified as C - Category projects (Black list) not B as mentioned before which means that a full Environmental Impact Assessment (EIA) Report should be carried out and presented on the proposed gasoline station by accredited consultants. The environmental impact assessment of the site, should include a geotechnical study and a hydrogeological and hydrological study that include:
  - Topographic Conditions and Buffer Distances (EU Regulations) (Cruz et al, 2017)
    - Sites must be protected against impacts from accidents and intentional damage. Concerning accidental damage, the topography at the intended site plays a major role.
    - Gas stations should not be located:

- In road turns (minimum distance: 100 m from inflection point; all road sections with curvature  $> 30^\circ$ ).
- On road sections with slopes  $> 10\%$ .
- Near schools, mosques, churches, monasteries, municipalities, supermarkets (buffer distance is limited to 50 m)
- Geoscientific Site Criteria Related To Geohazards (EU Regulations) (Cruz et al, 2017)  
Gas stations might be damaged by geohazards and could then develop severe leakages of petroleum products into the environment (air, soil, water). To avoid such environmental impact, gas stations should not be located:
  - Less than 50 m from the embankment of river courses (flooding risk).
  - Less than 50 m from tectonic faults with identified vertical displacement of  $> 1$  m (tectonic risk; earthquake risk).
  - Less than 50 m from slopes  $> 30\%$  (landslide risk; rock fall risk).
  - In areas of unstable underground (liquefaction risk, risk of land subsidence).
- Design and Selection of materials:
  - The use of double lining underground storage tanks to reduce the risk of gasoline leakage. The bulk delivery area as well the fuel handling areas which are susceptible to contamination must be provided with a pavement which is impermeable to hydrocarbons and other liquids (Australian Capital Territory, 2014).
  - Other areas outside the fuel handling area, may be surfaced with materials such a hot rolled asphalt, macadam etc.
  - The materials of the hard-standing areas should be periodically maintained over time to avoid leakage.
  - The use of corrosion protection materials in steel tanks and piping.

## Conclusions

Gasoline stations in Egypt could be a major source for the degradation of health quality for people who live and work in the neighborhood. The current evidence is sufficient to justify the application of the precautionary principle to protect people from the deleterious effects of living near environmental hazards. Even in the absence of complete scientific proof, enough evidence of potential harm do exist that justify taking steps to rectify the problem and to protect the public from potentially harmful exposures when all available evidence points to plausible risk. Although economic and political forces will likely require stringent proof that specific recommendations will be effective (e.g., establishment of protective buffer zones around noxious land uses), some practical applications should be obvious.

Based on findings, by applying the proposed guidelines, it would be possible to mitigate air pollution from gasoline stations in the Egyptian New Settlements, thereby contributing in the preservation of the environment, sustainable development and improving people's quality of life.

## Future implementations

A lot of work should be done in this field and this study should be carried in New Egyptian Settlements where it is planned to build these kinds of facilities, in addition, some sort of assessments of real estate values are required.

## References

- AQMD (2007). Emission Inventory and Risk Assessment Guidelines for Gasoline Dispensing Stations. California: South Coast Air quality Management District.
- Australian Capital Territory (2014). Environmental Guidelines for Service Station Sites and Hydrocarbon Storage Environment Protection Authority. Canberra: Australian Capital Territory (ACT) Government.
- CAPCOA (1997). Gasoline Service Station- Industry wide Risk Assessment Guidelines. California :Toxics Committee of the California Air Pollution Control Officers Association Air Toxics "Hot Spots" Program.
- Correa, S., Arbilla, G., Marques, M. and Oliveira, K. (2012). The impact of BTEX emissions from gas stations into the atmosphere. *Atmospheric Pollution Research*, 3(2), pp.163-169.
- Cruz, L., Alve, L., Santos, A., Esteves, M., Gomes, Í. and Nunes, L. (2017). Assessment of BTEX Concentrations in Air Ambient of Gas Stations Using Passive Sampling and the Health Risks for Workers. *Journal of Environmental Protection*, 08(01), pp.12-25.
- EBRD (2009). Sub-sectoral Environmental and Social Guidelines: Petrol/Gasoline Retailing, Petrol/Gasoline Retailing Sub-sectoral. Europe bank for reconstruction and development.
- EEAA (2001). Environmental Impact Assessment Guidelines for Oil and Gas Sector. Egypt: Egyptian Environmental Affairs Agency, Environmental Management Sector.
- Environment Institute. (1997). Total Volatile Organic Compounds (TVOC) in Indoor Air Quality Investigations. Report No 19. European Commission Joint Research Centre.
- National Institute for Occupational Safety and Health (2007). NIOSH Pocket Guide for Chemical Hazards. Publication No. 2005-149. Springfield: Centers for Disease Control and Prevention, Department of Health and Human Services.
- Smith, M. (2010). Advances in Understanding Benzene Health Effects and Susceptibility. *Annual Review of Public Health*, 31(1), pp.133-148.
- Steffen, C., Auclerc, M., Auvrignon, A., Baruchel, A., Kebaili, K., Lambilliotte, A., Leverger, G., Sommelet, D., Vilmer, E., Hemon, D., Clavel, J. (2004). Acute childhood leukaemia and environmental exposure to potential sources of benzene and other hydrocarbons; a case-control study. *Occupational and Environmental Medicine*, 61(9), pp. 773-778.
- Morales Terrés, I., Miñarro, M., Ferradas, E., Caracena, A. and Rico, J. (2010). Assessing the impact of petrol stations on their immediate surroundings. *Journal of Environmental Management*, 91(12), pp.2754-2762.
- U.S. Department of Health and Human Service (2007). Public Health Statement- Benzene. U.S. Public Health Service. Agency for Toxic Substances and Disease Registry, Division of Toxicology and Environmental Medicine.
- US EPA. (2017). Technical Overview of Volatile Organic Compounds | US EPA. [online] Available at: <https://www.epa.gov/indoor-air-quality-iaq/technical-overview-volatile-organic-compounds> [Accessed 20 July. 2017].
- World Health Organization (2000). Air Quality Guidelines for Europe. 2nd Edition. European Series No. 91. Copenhagen: WHO Regional Publications.
- World Health Organization (2010). Preventing Diseases through Healthy Environments, Exposure to Benzene: A Major Public Health Concern. Geneva: WHO Document Production Services.

# Determining Attributes of Public Space for Social Sustainability: The case study of Kushimato Street in Mersin

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**Abstract:** The academic works about social sustainability are mostly on urban units of larger scales such as neighbourhoods, the urban region and city or country level. The aim of this paper is focuses on the components of social interaction with discussing the attributes of good public spaces, through its viability and vitality of social spaces and the interactions within these spaces. For this reason we focused on a street which is a small scale built environment unit as the primary public space in city and identify the characteristics of social sustainability through literature review in Kushimato street which is a most vibrant in Mersin City. Self-administered questionnaires are carried out by asking the respondents to complete the questionnaire themselves. This study can be used by urban planners and designers to plan and make decisions for creating more socially successful and sustainable places in cities.

**Keywords:** Social Sustainability, public space, viability.

## Introduction

Public space has been always seen as an important part of social life. Urban designers seek to create liveable nodes to bring people together for various activities. Madanipour (2003) defines public space as a social capital which becomes an important part of society. Also it can promote social cohesion and prevent further fragmentation and atomization of the society (Madanipour, 2003). Saffer (2008), mentioned the fundamentals of public spaces as 'supporting physical activities, meeting friends or family, participating in leisure activities, enjoying nature and observing others' (Saffer, 2008). Since late 1990's, in Turkey, however public spaces have lost many of their functions in the social life of cities likewise all over the world. Madanipour (2006), expressed this, as reshaping urban space according to economic, political and cultural changes (Madanipour, 2006) Shopping malls are good examples of these reshaping. They are imitating the economic, social and spatial features of the public urban spaces (Özdemir et.al., 2016).

In the literature and academic works about urban spaces, parks and public spaces, social aspects of sustainability are rarely mentioned. The researches about social sustainability have always been focused on urban units of larger scales. These studies and researches has always interested in neighbourhoods, the urban region/district and city or country level.

From a social point of view, the sustainability of urban public spaces will be enhanced as long as they stimulate social cohesion and the creation of social capital. In terms of sustainable space, urban public space has an important role in a city. They are spaces of diversity, socially used and with free access and democratic conditions of use.

As Sivam et.al., (2011) mentioned the importance of socially activating street is crucial for people who use these spaces, and the sustainability of our cities as well (Sivam and Karuppannan, 2011). In this regards, vibrant streets have been always desired from the social sustainability point of view (Sense of community, participation to social life). For this reason we focused on a street which is a small scale built environment unit as the primary public space in city and identify the characteristics of social sustainability through literature review in Kushimato Street which is most vibrant in Mersin city. (Özdemir et.al., 2016). This paper aims to examine the characteristics of social sustainability in the urban area.

### **The Relationship Between Social Sustainability and Urban Public Space**

The relationship between the social interaction and the physical environment called 'The New Urbanism,' appeared in the early 1990s in the US (Wheeler, 2004). There are ten fundamental principles of New Urbanism: walkability, connectivity, mixed use and diversity, mixed housing, quality architecture and urban design, traditional neighbourhood structure, increased density, green transportation, sustainability and quality of life. The New Urbanism approach is based on enhancing diversity, walkability, and human scale environment, and "the goal of the Congress of Urbanism (CNU), founded in 1993, is to create buildings, neighbourhoods, and regions that provide a high quality of life for all residents, while protecting the natural environment" (Liang, 2010, p. 10). Talen (1998) emphasized that the aim of new urbanism design theory is building a sense of community (Liang, 2010, cited in New Urban News, 2009). According to Liang (2010), there are three fundamental principles: increased housing density, enhanced public open space, and developed design control and streetscapes (as cited in Adler, 1995).

There are different scales for the application of New Urbanism planning:

- "1. The metropolis, the city and town;
2. The neighbourhood, the district and the corridor;
3. The street, the block and the building" (Liang, 2010, pp. 10-11).

Integration of streets and public spaces in a living environment indicates the success level of a neighbourhood (Benfield, 2010). The pedestrian friendly approaches are accepted as one of the foremost indicators of success levels. Benfield (2010) states the determining factors as 'higher walkability, reduced automobile dependence, conserved land, and more opportunities for social interaction'.

According to the language of social theory, urban public spaces are both structured and structuring. The social construct of urban space is related to the activities, both cultural and economic, that are created by the people in their search for real sense of place. It is crucial both for designers and planners to understand the social construct of the community before judging the tools and means of creating social sustainability.

The discussions and the definitions of the social sustainability are widely in the literature. Chan and Lee (2008), defines social sustainability as maintenance and improvement of well-being of current and future generations (Chiu, 2003). Chiu (2003), mentions three main approaches to the definition of social sustainability. In the first approach she equates social sustainability to environmental sustainability that social aspect of sustainability of an activity depends upon specific social relations, structure and value, representing the social limits and constraints of development. According to her second approach which she called it as an 'environment-oriented', refers to the social preconditions required to achieve environmental sustainability. In the last approach she interprets it as 'people-oriented', refers to improving the well-being of people and the equitable



distribution of resources whilst reducing social exclusions and destructive conflict (Husseiny et.al., 2012).

Polese and Stren (2000:15-16) define the term as development that is compatible with harmonious evolution of civil society, fostering an environment conducive to the compatible cohabitation of culturally and socially diverse groups while at the same time encouraging social integration, with improvements in the quality of life for all segments of the population.

Social sustainability has been discussed in a wide variety of topics consisting layout, urban form and density, quality of life, well-being, social equity/justice, social cohesion, social exclusion/inclusion, social interaction, social and political participation, democracy and governance in the studies of academic works and literature (Colantonio, 2010; Dempsey et al., 2011; Littig and Griesler 2005; Chiu 2003; Polese and Stren 2000). In most of these works the common themes of social sustainability are;

Social Equity is access to key services, sufficient resources and opportunities for all of the generations (future generations will not be damaged by the activities of current generations)(Landorf, 2011; Bradley and Lee, 2005; McKenzie, 2004).

Quality of life is the well being of inhabitants in terms of social, environmental and economic factors. This term includes being well, happy and satisfaction.

In the Pride, sense of place and identity means people's perception and feelings of a certain place. Dempsey (2008), described the 'sustainable community' as an abstract term: providing 'a safe and healthy environment with well-designed public and green space' with 'a sense of place'. Sense of place or sense of community is a term used in everyday life and defined as 'feeling that members have of belonging and being important to each other and a shared faith members' needs will be met by commitment to be together' (McMillan & Chavis, 1986;8)

Social inclusion and coherence means to interact with the other members of community. It includes the cohabitation of culturally and socially diverse groups in communities to prevent social exclusion (Sedaghatnia et al., 2015; Colantonio, 2010; Chiu 2003; Polese and Stren 2000).

In this context, the urban design of cities and of their public spaces is a vital element of the all kinds of cities in means of reshaping urban space toward social and environmental sustainability. The majority of studies on social sustainability conducted on urban units of larger scales such as neighbourhoods, the urban region and city or country level. Streets as small scale built environment units are places for socialization and sharing which offer essential facilities to its inhabitants with their visual richness and aesthetics. Moughin (2003) defines the streets; 'The emphasis of streets is on movement between places, the principle lines of communication between different places. However the street is not only means of access but also an arena for social expression' (Moughin, 2003).

## **Research Methodology**

We conducted a questionnaire to the users (workers, visitors and residents) of Kushimoto Street to examine the street with influential urban social sustainability dimensions in public spaces such as quality of place, participation and accessibility, place of attachment, street amenity and heritage and local culture. Kushimoto Street is the commercial strip of the city of Mersin. Connecting to the Gazi Mustafa Kemal Boulevard and the other end of the street extend to the sea. With the accommodating diverse uses, the street plays an important role in the lives of city inhabitants especially university students.

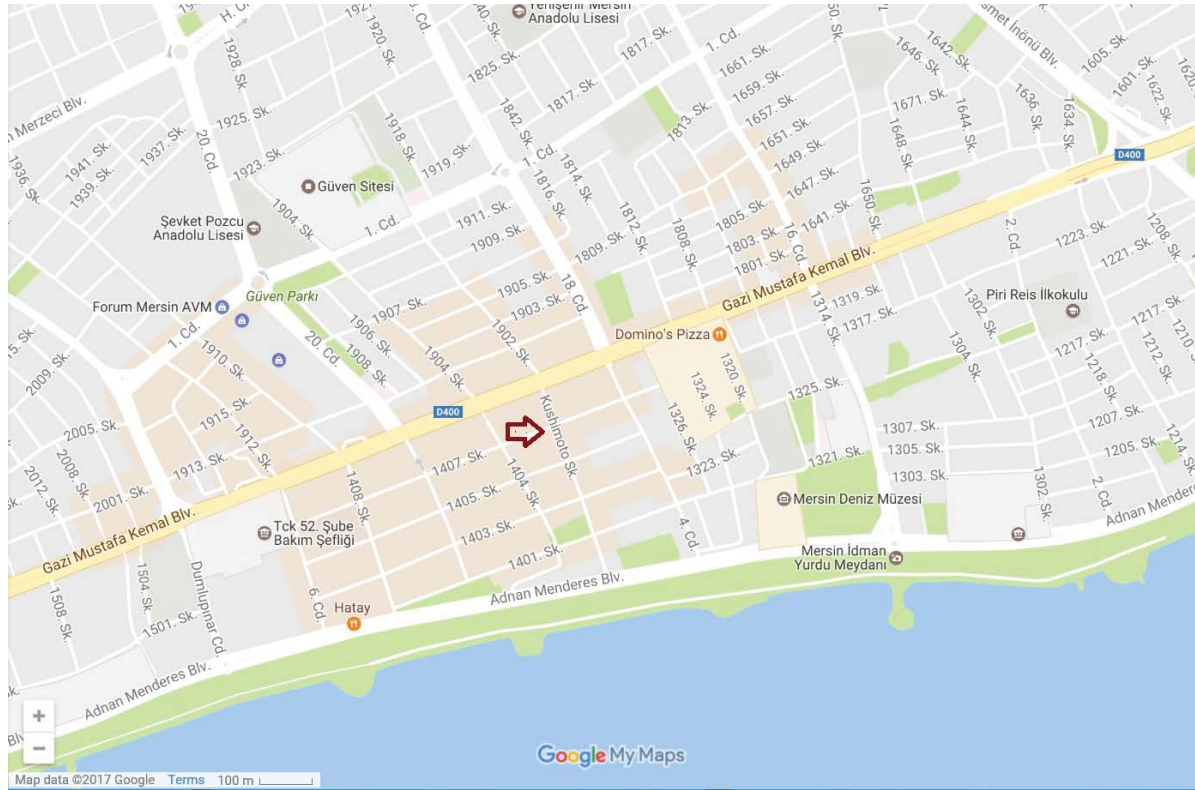


Fig. 1. Google map of Kushimoto Street



Fig. 2. Views from the Kushimoto Street

## Data Analysis

Data analysis in this study includes descriptive statistics, factor analysis and reliability analysis. Data was being entered to Statistical Package for Social Science (SPSS).

## Results and Discussions

Among a total of 149 respondents, gender distribution of respondents is %54,7 (82) male and %44,7 (67) female.

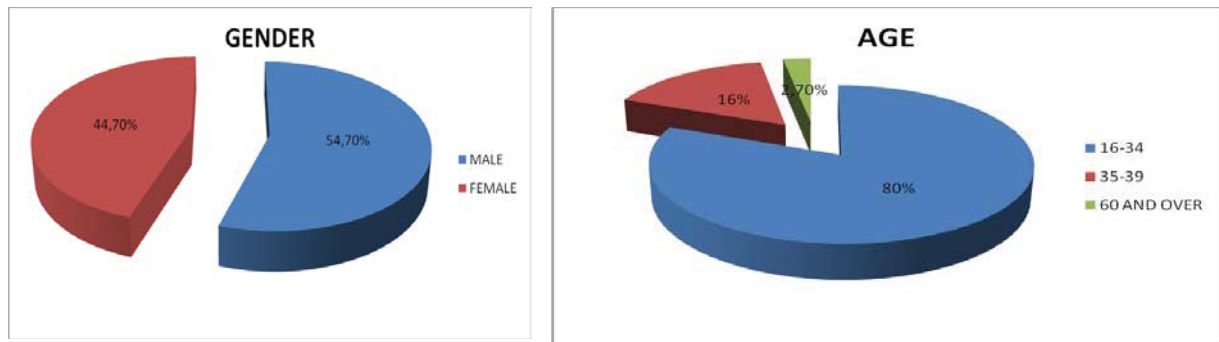


Fig. 4. Respondents' Profile

The majority of respondents' education level is university. (Fig.5). Kushimato Street, has been used especially for food and economic services. The users prefer to spend their leisure time here. This street is vibrant both in day time and night time. We can define this street as a pedestrian-oriented shopping street, fronted by buildings typically less than four stories height that serves as the principal commercial corridor in the city.

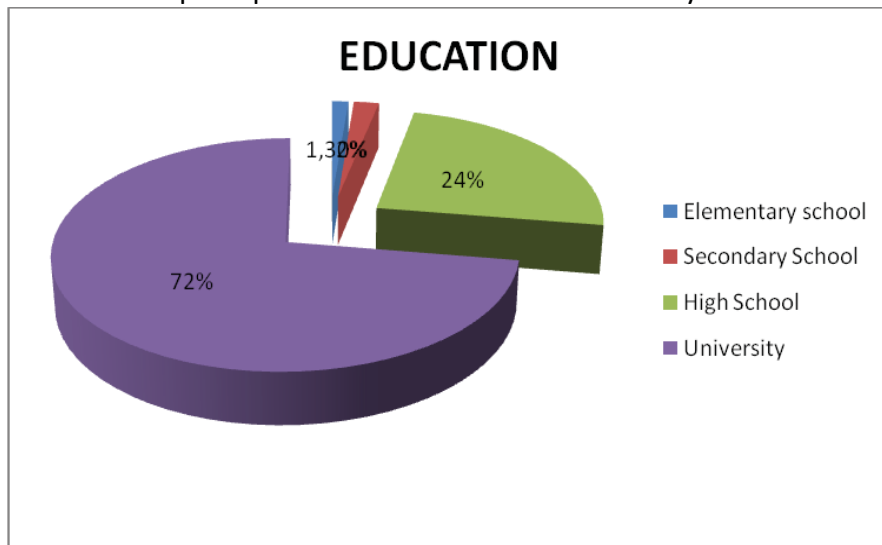


Fig. 5. Respondents' Education level

Participation and accessibility encompasses freedom of choices and provision of opportunities to socialize and participate in activities as well as access to building and places for users of varied ability and conditions

Accessibility approach also contributes to the sense of place development in neighbourhoods. Streets which are planned and designed according to details which contribute to the attractiveness and development of lively mixed-use places enhance the sense of place among the residents and visitors as well. The attractiveness of the place can be defined according to the variety of different functions particularly located in the ground floors of buildings. These functions which are open to the street and which invite people through their attractive design and functions (such as shops, cafes etc.) have the potential to enrich social interaction and mixed-use character of the environment (Government of Ireland, 2009). Accessibility to these facilities and strong connections between them contribute to the sustainability of the neighbourhood, which means that streets do not have only the movement function but more they have to be areas of social and cultural

interaction in order to support the neighbourhood and community sustainability (Government of Ireland, 2009).

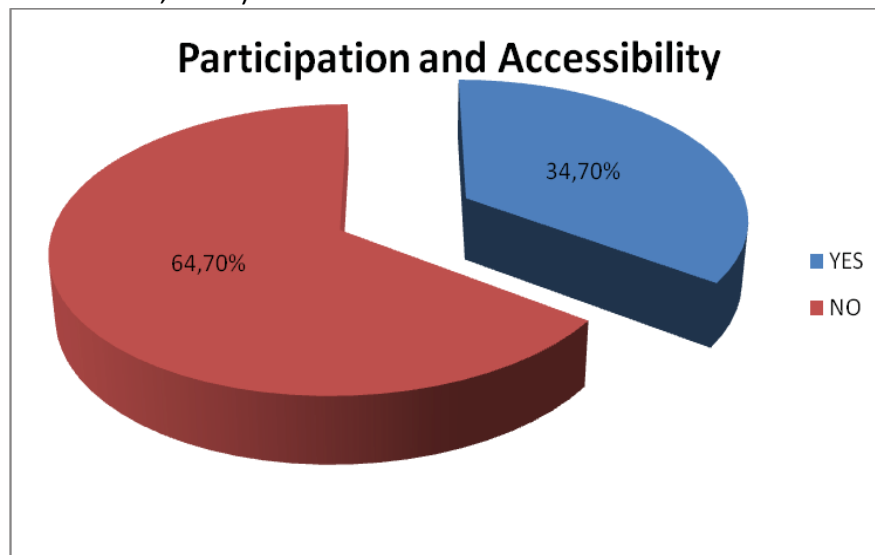


Fig.6. Participation and Accessibility

The place attachment is defined as a form of connection or bonding between a person and the setting. The significance of place attachment has been mentioned in several studies. Hartanti and Martokusumo (2012) emphasizes the influential role of the street as an urban identity. In terms of social sustainability, creating a sense of place is focused on social well-being. In our research, the users perceptions and feeling of this street is positive. (Fig.7.)

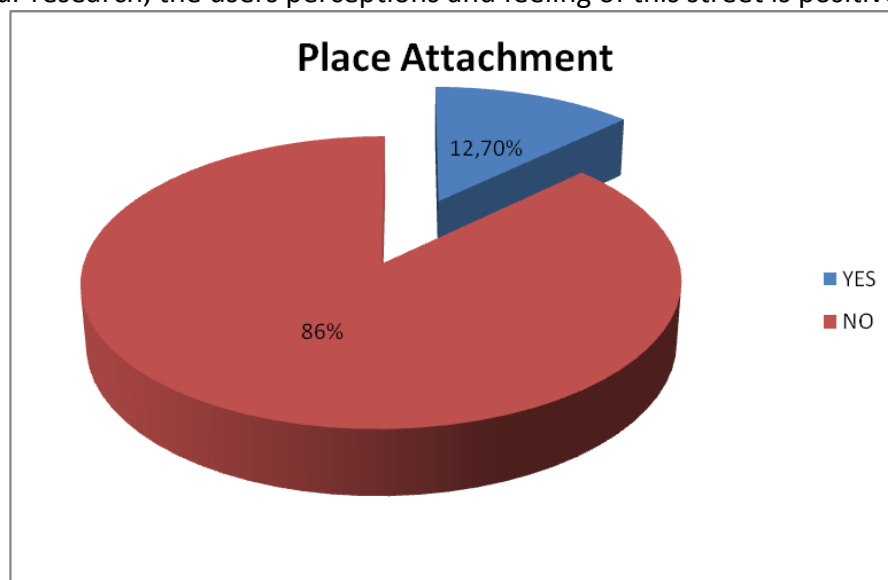


Fig.7. Place Attachment

Street amenity and heritage and local culture is mentioned in numerous studies in terms of social sustainability. Chan and Lee (2008) offers the condition of facilities and amenities for groups which have specialities such as the disabled, elderly and children. This is important also in terms of social equity and basic needs of inhabitants. Regarding streets' heritage, preservation of what remain from the past affects the social sustainability in a public space.

The findings reveal that there are several significant relationships that are important to the study, which are the Kushimato Street as: 1) a place to socialize 2) a place for relaxation 3) a place for a significant landmark for Mersin.

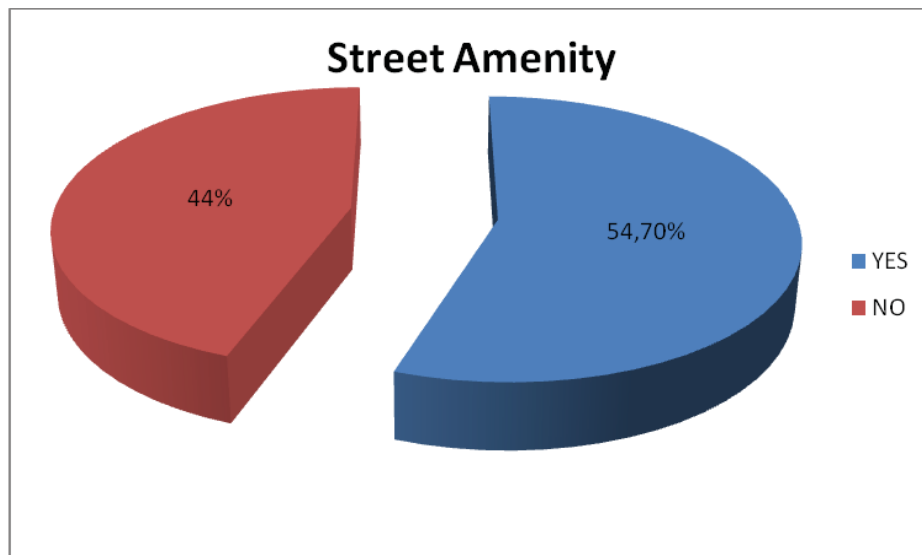


Fig.8.Street Amenity

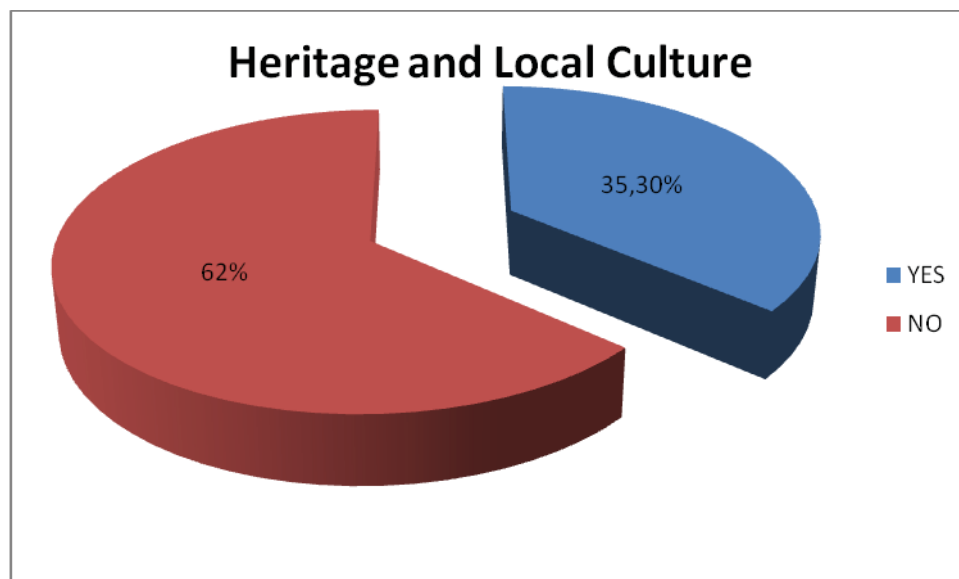


Fig. 9.Heritage and Local Culture

According to the factor of legibility, Kushimato street has an attractive views ability of vista and visual richness but on the other hand the buildings and places in the street has no well-defined characteristics with obvious functions and entrances. Regarding to the Kushimato Street through street amenity, the street is not available for disabled and old aged users. Users can not walk on the pavements. Pavements are used as a car parking area. For this reason the entrance of the buildings are closed with cars. This makes the street accessibility and participation difficult. Because the participation and accessibility encompasses freedom of choices and provision of opportunities to socialize and participate in activities as well as access to building and places for users of varied ability and conditions.



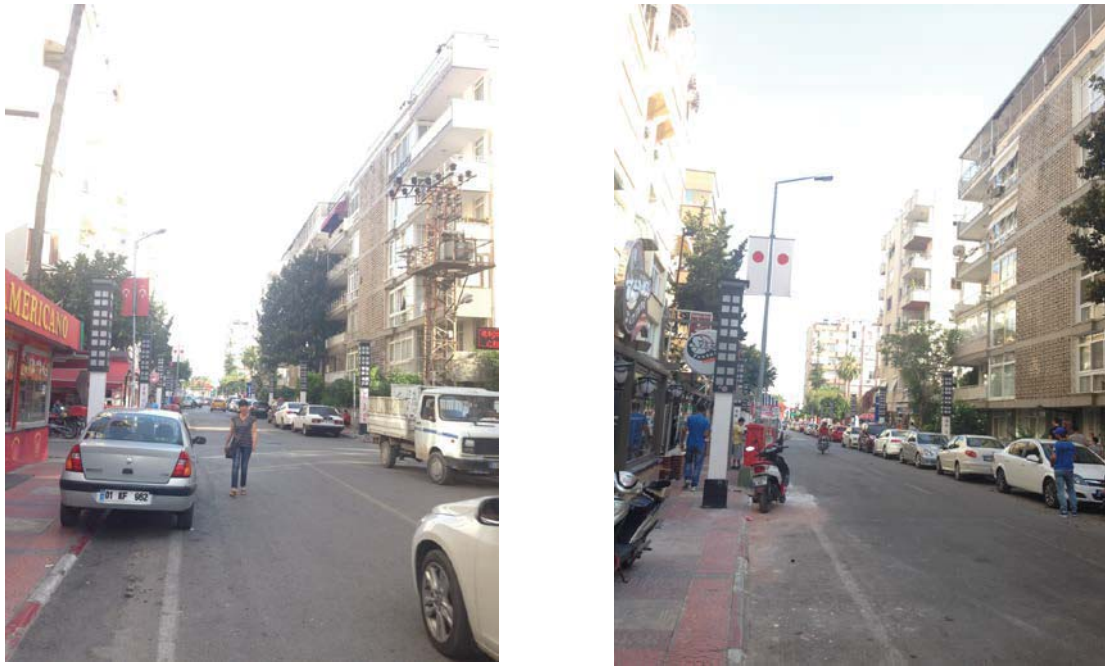


Fig. 10. Accessibility and the participation in the Kushimato Street

## Conclusion

In this research, we aimed to identify the social sustainability of a street. The social sustainability of public spaces dimensions has been indicated as; quality of space, participation and accessibility, place attachment, street amenity, heritage & local culture. Regarding to the Kushimato street some of these factors are weak for social sustainability like participation and accessibility. Because this street is not appropriate for the disabled and old aged people for their needs.

Streets, as a public space, should be planned and designed to meet the social needs of people and not only for traffic demands. This can be achieved by finding innovative traffic management and increasing open space and landscape in socially sustainable ways.

The social sustainability of architecture is a people-oriented interpretation. It refers to maintaining or improving the well-being of people for the present and future generations. The emphases are social cohesion and integrity, social stability and improvement in the quality of life.(Chiu,2003). Thus, there needs to be equitable distribution and consumption of resources, harmonious social relations and acceptable quality of life to be sustainable. This interpretation of social sustainability reminds us the principles of sustainable development defined by WCED in terms of equity and social justice for the present and future generations. Cultural sustainability is also mostly evaluated under the social sustainability of architecture.

As a conclusion, evaluating urban design characteristics of public spaces and their impact on social sustainability contribute local authorities, urban planners and designers to provide more socially successful and sustainable places in cities. When this social sustainability contributing factors are well acknowledged, monitored and improved in the current and future public spaces, it could be expected that such spaces could better serve their users of all kind and conditions for their wide range social and functional needs.

## References

- Benfield, K. (2010, December 1). *Lessons in neighborhood planning and architecture, from history and today*. Retrieved June 7, 2013, from SWITCHBOARD; Natural Resources Defense Council Staff Blog: [http://switchboard.nrdc.org/blogs/kbenfield/lessons\\_in\\_neighborhood\\_planni.html](http://switchboard.nrdc.org/blogs/kbenfield/lessons_in_neighborhood_planni.html)
- Chan, E. And Lee, G. (2008). Critical factors for improving social sustainability of urban renewal projects, *Soc Indic Res*, 85, pp. 243-256
- Chiu, R. (2003). Social sustainability, sustainable development and housing development: The experience of Hong Kong. In R. Forrest & J. Lee (Eds.), *Housing and social change: east-west perspectives*. USA: Routledge, pp.221-239.
- Colantino, A. (2010). Urban Social Sustainability themes and assessment methods. *Proceedings of the Institution of Civil Engineers: Urban Design and Planning*, 163 (2), pp.79-88.
- Dempsey, N. (2008). Does quality of the built environment affect social cohesion?, *Proceedings of the Institution of Civil Engineers Urban Design and Planning*, 161, pp. 105-114.
- El- Hussein, M.A. and Kesseiba, K. (2012). Challenges of Social Sustainability in Neo-liberal Cairo: Requestioning the role of public space, *Procedia-Social and Behavioral Sciences* 68 (2012) pp. 790-803.
- Government of Ireland. (2009). *Planning Guidelines: Sustainable Residential Development in Residential Areas (Cities, Towns & Villages)*. Retrieved June 18, 2012, from Environment, Community and Local Government: <http://www.environ.ie/en/Publications/DevelopmentandHousing/Planning/FileDownload,19164,en.pdf>
- Hartanti, N.B., & Martokusumo, W. (2012). Streetscape connectivity and the making of urban identity. Paper presented at the Arte-Polis 4 International Conference-Creative connectivity and the Making of Place: Living Smart by design.
- Landorf, C. (2011). Evaluating social sustainability in historic urban environments. *International Journal of Heritage Studies*, 17 (5), pp. 463-477.
- Liang, A. (2010, January). *Sense of Place: Urban Design, Amenity, Local Character and Heritage*. Retrieved November 1, 2011, from Sustainable Features: <http://www.wdc.govt.nz/PlansPoliciesandBylaws/Plans/SustainableFutures/Documents/Sustainable%20Society%20and%20Culture/30-50-Urban-Design-Amenity-Local-Character-and-Heritage.pdf>
- Littig, B., & Griessler, E. (2005). Social sustainability: a catchword between political pragmatism and social theory. *International Journal of Sustainable Development*, 8 (1), pp. 65-79.
- Madanipour, A. (2006). Roles and Changes of Urban Design, *Journal of Urban Design*, 11 (2), pp.173-193.
- Madanipour, A. (2003). *Public and Private Spaces of The City*. London: Routledge.
- McKenzie, S. (2004). Social Sustainability: Towards some definitions. Working Paper Series No 27. Hawke Research Institute. University of South Australia, Magill, South Australia.
- McMillan, D.W., & Chavis, D.M. (1986). Sense of Community: A definition and theory. *Journal of Community Psychology*, 14, pp.6-23.
- Moughtin, C. (2003). *Urban design Street and Square*, UK, Architectural Press in an imprint of Elsevier.
- Özdemir, E.E. and Cengizoglu, F.P. (2016) Public space Characteristics of contemporary Shopping Centers: The Case of Mersin Forum Shopping Center, *International Refreed Journal of Design and Architecture* Issue 7 Winter Spring, pp.
- Polese, M. And Stren, R. (2000), (Eds.), *The Social Sustainability of Cities: Diversity and the Management Change*, University of Toronto Press, Toronto.
- Saffer, H. (2008). The demand for social interaction. *Socio-Economics Journal*, 37, pp. 1047-1060.
- Sivam, A., & Karuppanan, S. (2011). Social sustainability and neighbourhood design: an investigation of residents' satisfaction in Delhi. *Local Environment*. 16(9), pp. 849-870.
- WCED. (1987). *Report of the World Commission on Environment and Development: 'Our Common Future'*. Retrieved April 29, 2009, from United Nations (UN): <http://www.un-documents.net/wced-ocf.htm>
- Wheeler, S. M. (2004). *Planning for Sustainability: Creating Livable, Equitable, and Ecological Communities*. Abingdon: Routledge, Taylor&Francis Group.

# Rebuilding communities through the arts: Private enterprise art patronage that contributes to the sustainability of local communities in Japan

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**Abstract:** Despite the emerging trend of counterurbanization, many communities in Japan are facing depopulation. The Japan Policy Council recently issued a report stating that nearly half of all the municipalities in Japan will disappear in the near future.

Parallel to the counterurbanization movement, many contemporary art projects have appeared in rural areas since 2000, such as the Echigo-Tsumari Art Triennale and the Setouchi International Art Festival. These projects have had a major impact on local economies, attracting public/private investment to the area and drawing a large number of visitors. Although the public sector seems to be leading the current trend, private enterprise has begun supporting community-oriented art projects like these, as artists become increasingly engaged in the issues of declining communities. This paper explores the pioneering practices of private enterprise art patronage that contributes to sustaining local communities in Naoshima, Inujima, Momoshima, and Kosagijima, islands located in the Inland Sea of Japan. These are typical of islands with rapidly aging rural communities facing severe depopulation.

As private enterprise art patronage has begun to encompass community art projects, it has taken on a significant role in sustaining local communities. Such projects form the basis of the current trend toward community-oriented public art programs in rural areas. Although initially private enterprise may not always have been interested in the sustainability of local communities, artists and art projects concerned with communal issues have inspired business to engage with these communities. As examples, these islands display different frameworks that genuine private art patronage has transformed into community-oriented investments.

**Keywords:** sustainable community, art patronage, the Inland Sea of Japan,

## Introduction

The decline in Japan's population that began in the 2010's has been accompanied by a trend of counterurbanization and a popular move to rural areas (Figure 1). The Japan Policy Council recently issued a report (Masuda 2014) stating that nearly half of all the municipalities in Japan would disappear in the near future. The report draws urgent attentions for the issues of depopulation.

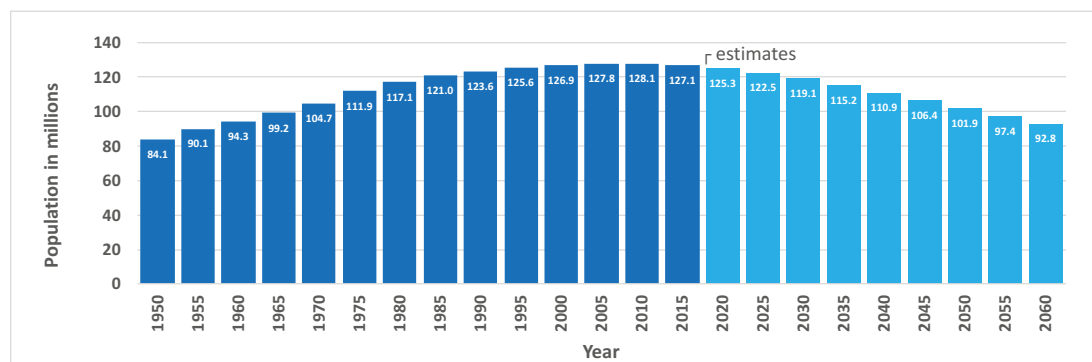


Figure 1. The population of Japan. Based on the *Information and Communications in Japan 2017 White Paper* (Ministry of Internal Affairs and Communications)

With the future of many rural communities at stake, the trend of migration to rural areas is expected to go some way toward solving this issue (Yagi, 2010a). A considerable number of people has moved from metropolitan areas to western parts of Japan, especially

after the 3/11 earthquake in 2011. The coastal area of the Inland Sea of Japan has been one of the major destinations for these migrants (Figure 2).

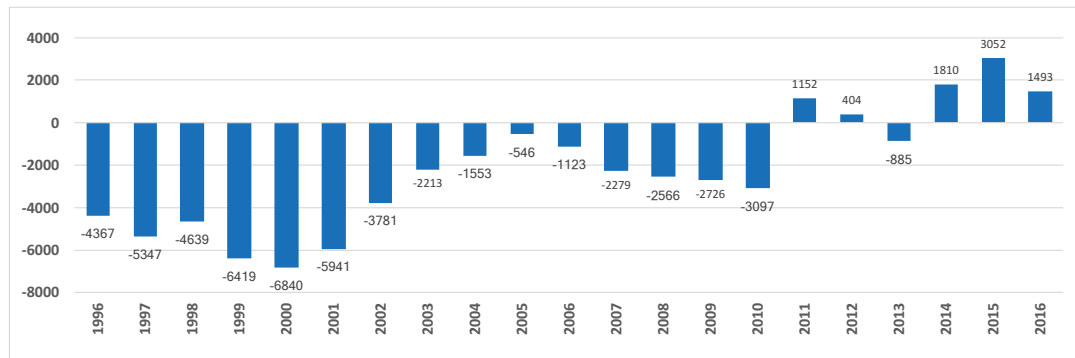


Figure 2. Migrants in Hiroshima Prefecture. Based on population statistics. (Hiroshima Prefecture, 2017)

In the meantime, public art programs in Japan have gradually changed in form from permanent outdoor sculpture installations to more socially engaged temporary art exhibitions (Takeda and Yagi, 2001). New genre public art (Lacy, 1995) has finally found its place in Japan. The Echigo-Tsumari Art Triennale and the Setouchi International Art Festival are among the most successful examples of this, drawing millions of visitors to the rural areas of Japan (Kitagawa, 2015). Art projects like these in the coastal areas of the Inland Sea of Japan have started to change community and local economies (Yagi, 2010b).

This paper explores the pioneering practices of art patronage by private enterprise that contribute to sustaining local communities in Naoshima, Inujima, Momoshima, and Kosagijima, islands located in the Inland Sea of Japan. These islands are typical of declining rural communities, facing rapid aging and severe depopulation.

## Islands

This section describes the four subject islands located in the Inland Sea of Japan: Naoshima in Kagawa Prefecture, Inujima in Okayama Prefecture, and Momoshima and Kosagijima in Hiroshima Prefecture (Figure 3).



Figure 3. Location of the islands. Based on the image published by Geospatial Information Authority of Japan.

### ***Naoshima***

Naoshima is a relatively large island in the Inland Sea of Japan and is located between Okayama city and Takamatsu city in Kagawa Prefecture. It has about 3,000 residents.

There are two regular surface transport routes, about 20 minutes from Uno port near Okayama city or 60 minutes from Takamatsu port.

Naoshima once flourished because of its salt manufacturing; however, since then its population has declined; it has lost more than 1,000 residents in 20 years. Major industries are a copper refinery and a disposal plant that handles large volumes of illegal industrial waste from nearby Teshima island. It has become a resort island as a result of art-oriented development for the past 25 years.

### ***Inujima***

Inujima is a small island located within Okayama city. It is the only inhabited island in Okayama city and has population of 46.

Inujima was once a major stone quarry that provided construction materials for castles and shrines. It flourished with a copper refinery between 1909 and 1919 with a peak population of about 1,500. However, after the copper refinery discontinued operations, large scale brick structures were left abandoned until 2008 (Figure 4).



Figure 4. Abandoned ruins of the former copper refinery plant in Inujima in 2004.

There is a regular surface transport from Hoden port, east of downtown Okayama city. A trip to Inujima takes only 10 minutes, but it takes about an hour from downtown Okayama to Hoden port.

### ***Momoshima***

Momoshima is another relatively large inhabited island in the Japan's Inland Sea as part of Onomichi city. It currently has about 500 residents. Although shipbuilding and saltworks were major industries of the island, they have now discontinued their operations. As the population progressively decreased, many houses and buildings, such as movie theater and schools, were left abandoned (Figure 5).





Figure 5. Abandoned movie theater as of 2012.

There are two regular surface transport routes, about 30 minutes from Onomichi port or 10 minutes from Tshuneishi port.

### ***Kosagijima***

Kosagijima is a small island that is part of Mihara city. It currently has only five regular residents, although more than 500 people lived there at its height. Its major industry was wooden boatbuilding, but the introduction of fiberglass boats swept this completely away.

There is a large quarry site that provided the construction material for the Kansai International Airport reclamation and was abandoned after that (Figure 6).



Figure 6. Former stone quarry at the northern part of Kosagijima.

There is a regular surface route, and it takes about 15 minutes from Mihara port.

## Projects and private patronage scheme

This section discusses each island's projects and the patronage schemes that help to sustain the local community.

### ***Naoshima***

The president of the Okayama based Fukutake Publishing Corporation (later Benesse Corporation, which provides popular educational materials for children) envisioned a gathering place for children from all over the world in the Inland Sea of Japan. The Mayor of Naoshima dreamed that the southern part of Naoshima would be developed as an educational and cultural area. A meeting of these two people led to a series of developments around Naoshima (Benesse, 2016).

In July 1989, the Naoshima International Camp Site was started. A sculpture placed in the campsite was the first outdoor contemporary artwork in Naoshima.

Three years later, Benesse Corporation opened Benesse House and the Naoshima Contemporary Art Museum, designed by architect Tadao Ando, followed by the Art House projects and several other museums, including the Chichu (i.e. underground) Art Museum (Yagi, 2010b). Some of these projects were part of Benesse Corporation's social responsibility activities, while others were funded by the Fukutake Foundation, established by the president of Benesse Corporation.

The museum buildings were carefully designed to minimize the impact on the rural landscape (Figure 7). The small-scale Art House projects utilize existing local houses that have often been vacant for a long time (Figure 8). Traditional Japanese wooden houses can easily decay if they are not maintained. Therefore, Art House projects in Inujima utilizing vacant houses offer good support by sustaining the local community while maintaining the townscape.

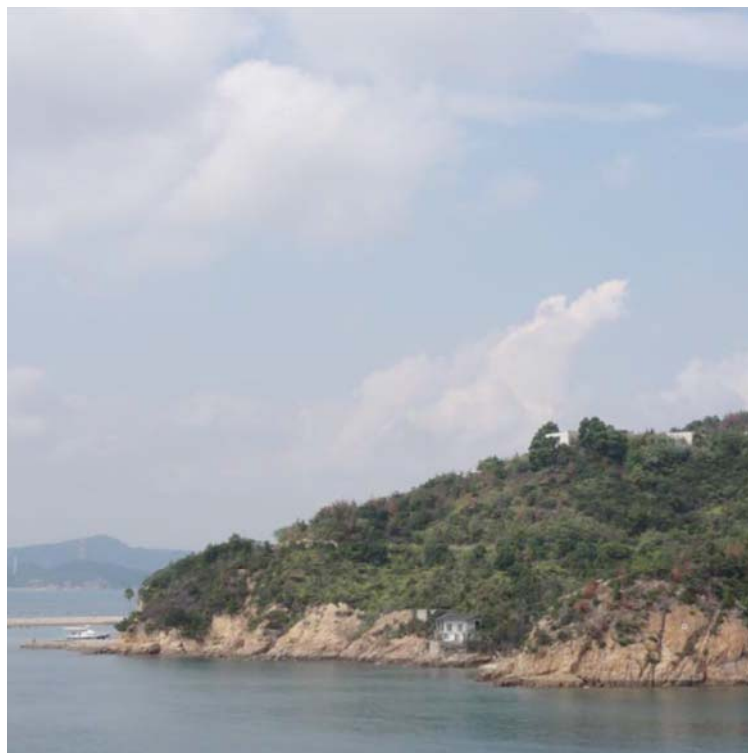


Figure 7. The barely visible Chichu Art Museum in Naoshima.



Figure 8. Tatsuo Miyajima's site-specific permanent art installation utilizing an existing local house.

### *Inujima*

Then New York based Japanese artist, Yukinori Yanagi, visited the Inland Sea of Japan and encountered the ruins of the former copper refinery in 1995. He found the structure suitable as a subject for his creative work. Yanagi proposed his vision of reclaiming the abandoned site to Soichiro Fukutake, the president of Benesse Corporation. Yanagi moved to Ijujima and over several years he developed his vision for the former refinery site. As a long-time patron of Yanagi's artwork, Soichiro Fukutake agreed to sponsor Yanagi's plan and purchased the refinery site to make the plan a reality. (Yanagi, 2010)

Fukutake invited architect Hiroshi Sambuichi to turn the refinery ruin into a museum exhibiting Yanagi's site-specific artworks. The Inujima Seirenscho (i.e. refinery) Museum eventually opened in 2008 (Figure 9). The museum is carefully designed to preserve the richness of the cultural heritage of the modernization period.



Figure 9. The Seirenscho Art Museum reclamation of a former copper refinery.

The Seirenscho Art Museum was followed an Art House projects, as in Naoshima; however, the Art House project in Inujima utilized vacant lots and introduced new

structures into the community. Although some of the super-modern new buildings designed by architect Kazuyo Sejima look like quite alien in the rural landscape (Figure 10), the Art House project occupying former vacant and unmaintained lots does contribute to the community.



Figure 10. Art House project in Naoshima. Introducing new structures into a traditional townscape.

In 2010, Fukutake invited the adjoining prefecture government and Fram Kitagawa, an art curator who was renowned for the success of the Echigo-Tsumari Art Triennale, to launch a public-private joint art project, the “Setouchi International Art Festival.” Since then, the Setouchi International Art Festival has been held every three years and has attracted millions of visitors to the rural communities around the Inland Sea of Japan. It has a huge impact on the local economy.

### ***Momoshima***

After the completion of the Seirenscho Art Museum in Inujima, Yanagi looked for somewhere around the Inland Sea area for his creative work space. Onomichi city offered him the former Momoshima junior high school, and he remodeled the school building by himself into gallery and studio.

The project was funded by the patronage of his collectors and a private enterprise business run by the Momoshima/Onomichi-born president, with funding from other public/quasi-public bodies. The art center “Art Base Momoshima” was opened in 2012 (Figure 11).

After opening the art center, Art Base initiated annual exhibitions using vacant houses around its neighborhood. Vacant houses are maintained and remodeled as required to become artists’ residences and art exhibition spaces. Art Base further expanded its exhibition space into several large abandoned buildings in the community. The second institution was the movie theater mentioned previously (Figure 5). Yanagi remodeled the abandoned theater on the main street of the island into an exhibition space for his illumination art work (Figure 12).

Art Base staff and resident artists not only utilize abandoned space, they also actively participate in local events as community members, and even helped to revive a local festival that had not been seen for decades.





Figure 11. Gallery space in the former junior high school. Copyright Yukinori Yanagi/Art Base Momoshima.



Figure 12. Exhibition space utilizing the abandoned movie theater. Copyright Yukinori Yanagi/Art Base Momoshima.

### ***Kosagijima***

After ownership of former quarry site in the northern part of the island had changed hands several times, the nearby Fukuyama city based Pueq Corporation purchased the site to save it from becoming an industrial waste landfill.

Pueq Corporation's business consultant happened to meet Yukinori Yanagi, and invited him to develop a vision for the island. In 2009, Yanagi proposed the "Kosagijima Bio-Isle Project" plan, which envisioned reclaiming the island as a living whole.

Pueq Corporation support the Bio-Isle project as a part of their social responsibility activities. Later they established the Pueq Satoumi Foundation as a driving force for the project to make it independent of their corporate performance, although Pueq Corporation and its executives are still major donors to the Foundation. Their mission includes planting trees around the island (Figure 13), and maintaining the abandoned houses, house lots, and farmlands. They have remodeled several vacant houses on the island into a studio, gallery space, and guest house (Yagi, 2017).





Figure 13. Planting trees around the island.

In 2015, the foundation held an art exhibition using these remodeled houses. The 40-day exhibition attracted thousands of visitors to the island (Figure 14). As a result of this successful event, the surface transport services between Kosagijima and Mainland increased, reducing the isolation of the community.



Figure 14. The special exhibition attracts quite a few visitors to the island.

## Conclusion

Although the projects on four islands have different private funding and patronage schemes, from small to large scale, all these projects take a long period of time to realize, sometimes more than 10 years. It took time for the art projects to be recognized as a real part of the local community. (Akimoto and Henmi, 2002)

As private enterprise projects, the progress of these projects has been slow. Other similar contemporary art projects have been seen as conflicting with the local community;

unlike these, the successful projects described here have been prepared to take the time needed to satisfy the local community and secure its willing cooperation. This is an essential part of these projects.

Soichiro Fukutake, the president of Benesse Corporation, played an important role in encouraging this trend of local art projects. Many local enterprise executives respect him as a role model. Pueq Corporation is not the exception and, one after another, many younger entrepreneurs in this area have followed his lead.

Art projects around the Inland Sea of Japan area have been instigated by the private sector pioneering the use of abandoned space and buildings in the declining community. The projects that result support essential communal activities and services that the declining community could not otherwise maintain. Patronage of these art projects has made a substantial contribution to the sustainability of local communities at a time when public funding is static.

Recognizing the outstanding success of art projects like these, more and more public-sector organizations are joining this trend. However, it is very important to remember that all these projects took a long time to realize their vision. Unreasonable demands for an immediate outcome would only lead to the destruction of the local community. Art projects are not a way to prop up a dying community, but the common ground and a common vision of that community's future.

## References

- Akimoto Y. and Henmi Y. eds. (2002). *The Standard*. Okayama: Naoshima Contemporary Art Museum.
- Benesse Art Site Naoshima (2016). *History of Benesse Art Site Naoshima*. [online] Benesse Art Site Naoshima. Available at: <http://benesse-artsite.jp/en/about/history.html> [Accessed 30 Sep. 2017].
- Hiroshima Prefecture (2017). *Population Statistics*. [online] Hiroshima Prefecture. Available at: <https://www.pref.hiroshima.lg.jp/site/toukei/jinkoudoutyosa.html> [Accessed 18 Nov. 2017].
- Kitagawa, F. (2015). *Art Place Japan: The Echigo-Tsumari Triennale and the Vision to Reconnect Art and Nature*. New York: Princeton Architectural Press.
- Lacy S. ed. (1995). *Mapping the Terrain: New Genre Public Art*. Seattle: Bay Press.
- Masuda, H. (2014). *The Death of Regional Cities: A horrendous simulation Regional Cities Will Disappear by 2040 A Polarized Society will Emerge*. [online] Japan Policy Forum. Available at: <http://www.japanpolicyforum.jp/archives/politics/pt20140120152454.html> [Accessed 30 Sep. 2017].
- Ministry of Internal Affairs and Communications (2017). *White Paper Information and Communications in Japan*. [online] Ministry of Internal Affairs and Communications. Available at: <http://www.soumu.go.jp/johotsusintokei/whitepaper/ja/h29/html/nc135230.html> [Accessed 18 Nov. 2017]
- Takeda, N. and Yagi, K. (2001). Management of Aesthetic Intentions in Urban Design, *Journal of Korean Institute of Landscape Architecture, International Edition*, No. 1, pp.167–175.
- Yagi, K. (2010a). A Multiple Residence Framework for Sustaining an Insular Community, *Proceedings of the 8th International Symposium on Architectural Interchanges in Asia*, pp.663–pp.666.
- Yagi, K. (2010b). Art on Water: Art that revitalizes Insular Communities Facing Depopulation and Economic Decline, *Nakbara: Journal of Environmental Design & Planning*, Vol. 6, pp.119–130.
- Yagi, K. (2017) Renovating Abandoned Houses for Sustaining a Declining Community in Japan, *Proceedings of the 33rd PLEA International Conference, Vol. I*, pp.320-327.
- Yanagi, Y. (2010). *Inujima Note*. Tokyo: Miyake Fine Art.

# Mobility and the Role of Pedestrian in the Making Public Space

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**Abstract:** The paper aims to evaluate and criticize literature on public space and planning in terms of the role of pedestrian and mobility in the making public space. The main question of the research is What is the role of pedestrian and mobility in the making public space (space to place progress)?

The study primarily underlines literature review on public space, mobility and pedestrian behaviour in urban planning. Literature review of the study would be examined as three main parts. Firstly, main discussions, theories and terms related with public space are evaluated. Secondly, the literature is criticized according to recent circumstances and contemporary discussions. Lastly, especially, the terms of mobility and pedestrian movement in public space regarding urban planning are evaluated.

In defined context, the recent seaside of Mersin that has been formed by different filling operations since the beginning of 20th century is selected as case study. In other words, case study area is a recently produced space while the city has been expanded.

**Keywords:** Public Space, Mobility, Pedestrian Movement, Pedestrian Behaviour, Seaside of Mersin

## Introduction

The study is prepared to evaluate and criticize literature on public space and planning in terms of proposed research that focuses on the role of pedestrian and mobility in the making public space.

Public space is a term has been transformed, expanded or shrunk. Primarily, public space would be evaluated as squares and streets those are belonged to whole society and used by all citizens, mostly freely. In addition to these, recreative areas, parks, seaside or most of the open spaces or public buildings like schools, administrative centres, so could be evaluated as varying forms of public space. Recently, private public space like shopping mall is a discussion topic for social sciences, too. In any time, planning and designing of public space is a fundamental topic in literature. However, in terms of ownership or publicity, could all public spaces be efficiently accessed and used by everyone? ...that is a crucial discussion. Especially, the role of pedestrian, which is the most basic model to use a public space, is critical to determine identity of space in terms of accessibility.

The **main question** of the research is What is the role of pedestrian and mobility in the making public space (space to place progress)?. The **sub-questions** of the study are What is public space, how could public space conceptualize as a socio-spatial term?, How can be mobility and pedestrian behaviour measured in public space? and What is pedestrian? (How the term of pedestrian has been developed? / Pedestrian as a mode of transportation)

Furthermore, the context and methodology of study is determined in terms of case study researches. In addition, case study, the seaside of Mersin is briefly discussed as a recreational public space and a pedestrian focus.

Recent seaside of Mersin has been formed by different filling operations since the beginning of 20th century. In other words, case study area is a recently produced space while the city has been expanded. However, while some areas in same context are efficiently used, some zones could not be used or ignored by pedestrians. Therefore, the seaside of Mersin is the best example to discuss the role of pedestrian movement and mobility in terms of planning and urban design affecting making public space.

In the study, instead of approaches, which see the pedestrian movement in public space is mostly discussed with space-syntax approaches or pedestrian is evaluated only as a mode of transportation with technical qualities, the study primarily focuses on quantitative attributes of public space, qualitative characteristics of public space based on human factor as a socio-spatial term are going to be investigated. Similarly, mobility management measures (Kristensen and Marshall, 1999) will include not only non-physical but also qualitative terms like design quality in public space are going to investigate.

## **General Discourse**

### ***Public Space / Conceptualising public space***

Gehl determines open-area activities in three main groups. First group includes; walking, dining, waiting or shopping for daily needs like working, education or child care. Optional activities like walking, looking, sitting or running are described as second group within appropriate time and place. Last group is basically defined as social and cultural activities. These outdoor activities compromise varying modes and relations with surrounding environment, but basically could be evaluated as public space (Gehl, 1996 cited in Carmona et al., p.11, 2008). In the following parts, firstly, the development of public space is evaluated from antiquity to contemporary discourse.

#### ***History of Public Space***

In the antiquity, the market place, square or any word in any language exactly covers the word of Agora. In Greek City-States, agora was an area for free citizens to administratively or commercially determines their public needs. Densely and strict use of agora described a primitive experience for public space (Wycherley, p.45, 1993). Similarly, Carmona (et al., pp. 23-42, 2008) evaluates public space through history, especially Western public space from antiquity to renaissance and baroque till modernism.

#### ***Public Space in Turkey***

The development of public space in Turkey will be evaluated as modernization movements after the 19<sup>th</sup> century, the Late Ottoman Period, planned modernization in especially Early Republican Era and contemporary debates, which especially include shopping mall and social movements debates together since June 2013, Gezi Parkı protest.

- Late Ottoman Modernization;
  - Historically evolved public space.
- Early Republic Modernization;
  - Planned development.
- Contemporary Debates;
  - Motorized traffic and misuse in public space.
  - Social movements' area.
  - Shopping malls and gated communities.

#### ***Contemporary debates and public space***

Akkar Ercan and Memlük (pp.195-198, 2015) underline two groups of arguments on public space literature. The first one is determined as critical scholars evaluating public space within the terms of publicness and inclusivity and mention about privatization, co-modification and commercialization of public space, which mostly crucial elements in urban restructuring. The second group concentrates on who and public to determine forms,

inclusive processes of production, management, local communities, civic rights and daily life routines. Contemporary debates about public space focus on ideal or inclusiveness of space in cities.

Carmona (et al., p.43, 2008) determines a bundle of critique of contemporary urban public space changing from physical decline to social discussions. Neglected space, lost spaces, 24-hour space, invaded space and exclusionary space are used as terms to underline physical dimension of public space in general terms. After that, privatization, manufacturing, consumption or segregation in public space is evaluated terms in current discourse. This approach lets to classify urban space according to nature and users.

Public spaces within each neighbourhood, such as open spaces, streets and gathering places, are key factors to create liveable communities (Gehl 1995, cited in Montgomery p.110, 1998) claims that "the streets are undoubtedly the most important elements in a city's public realm, the network of spaces and corners where the public are free to go, to meet and gather, and simply to watch one another". In similar context, Marshall (p.6, 2005), determine three physical roles of street as circulation route, public space and built frontage (Figure 1).

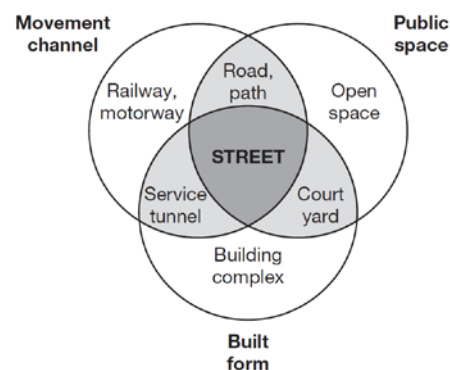


Figure 1: The elements of the street

### *Space or Place*

Resuloğlu (pp.29-31, 2011) underlines the differences between the words "space" and "place", but discuss the concept of publicness defining a group of people, which have an identifiable characteristic. "When a "space" or a "place" is qualified by the concept of "public", this means that it is defined as a three-dimensional entity to be experienced by a certain group of people." Place is mostly used to determine a location have social meanings. Similarly, same definition could be used for space culturally defined or experienced environment (Lefebvre, 2014).

Public space plays an important role by allowing interaction between people to determine the city's identity and character. In defined context, experience of being a citizen is obtained in public space by daily practices and social life.

Today's, globalization and different forms of economic and politic dynamics change recent geography into new spaces. New relationships are also emerged by produced new spaces.

In defined context, specific features of local gain value by varieties of geographies and localities. These differences result with different spatial references and economic, social or political changes creates transformation in spatial terms. The cycle changes and transforms the space, transforming and changing spatial economy, politics, social life and contributes.

Lefebvre (2014) states that, social space is a social product and information create space. On the other hand, **practice** including daily routines, **representation of space** focuses



on maps, plan and design and **representational space** compromising ideals, imaginations and so on.

Tekeli (p.19, 2008) says that Lefebvre as a high predictive social scientist, if social relations of production are spatial, it could be really social that means social relations are embedded to space while produced (Lefebvre, 1991 cited in Tekeli, p.19, 2008). Space is produced together with social. At that point, it is accepted that the spatial through social events cannot be excluded while spatial does not exclude social, too (Tekeli, p.19, 2008).

#### *'Publicness' of public space*

As mentioned before, Gehl has characterised outdoor activities into three categories as, necessary, optional and resultant (social) activities. Extensive research indicates that necessary activities are partially influenced by the quality of public space because of necessities for life to continue. On the other hands, optional ones are directly related with conditions are optimal or not. Moreover, perception of space is affected by liveability. People choose to stay long or not (Gehl, 1996 cited in Carmona et al., p.11, 2008).

The quality discussion in public space could be described as publicness (Akkar, 2005) of a public space. In general terms, the term of public includes meanings of whole, open to all, accessible or shared by whole society (Gove, 1976 and Makins, 1998 cited in Akkar, p.2, 2005). Therefore, its openness to whole society is crucial define an area as public space. Akkar and Memlük (pp.196-198, 2005) discuss accessibility of space as inclusivity and state that there are varying factors on the inclusivity of public spaces.

Akkar (2005) describes four dimension of accessibility as physical access, social access, access to activities and access to information to determine inclusivity of public space. Physical access is basically defined as universal access to physical environment (Tiesdell and Oc, 1998 cited in Akkar, 2015). Social access relates with who is welcome or not in the space (Carr et al., p. 149, 1992 cited in Akkar, 2015). Access to activities or uses and its variety let to mix social groups and inclusivity. Lastly, access to information, discussions and intercommunications related with the management of public space for ongoing and future events and activities, as well as the design, planning, development, management, control and use processes on public space. These factors may be evaluated as physical and procedural dimensions to define public space (Akkar, 2005).

#### **Pedestrian Movement in Public Space**

The publicness of public space is a qualitative discussion. Therefore, in terms of planning, the quality of life and liveability should be evaluated according to the role of movement of pedestrian and mobility.

In the HABITAT II Turkish National Report and Action Plan, sustainability, liveability and justice were selected as the basic principles for human habitats, while civic engagement, enablement and governance were selected as the instrumental principles. In the report, sustainability is defined as a condition that should be performed. Liveable habitation, at the same time, should be sustainable, fair and equitable. In the report, liveability is defined as a term which is related to not only individual and social well-being, happiness, but also spatial characteristics and qualities of human settlements that directly contribute to the satisfaction of people living in a settlement. All these terms are closely related to human rights. Especially liveability is the spatial dimension of human rights.

In the HABITAT Agenda, the concept of liveability is used to refer to the quality of life (QoL) which is closely related to the spatial and physical features of our living environment, as well as social and economic factors. This term directly affects the organization of land-use pattern, building and population densities in urban space, architectural style, the accessibility of public spaces. This section aims to explore the notions of 'quality of life' and 'liveability' as the key components of sustainable urban development. After setting up a relationship between walkability and these terms, it will explain the concept of walkability and a set of criteria to measure the walkability capacity of urban environment in detail.

Mobility is defined as "The ability to move between different levels in society or employment" in the Oxford Dictionary (<http://www.oxforddictionaries.com/definition/english/mobility>). For that reason, mobility is regarded as an ability of movement. Providing mobility is related to the accessibility.

Urban mobility in most cities of the developed world is changing because of technological innovation, socio economic change, new policy interventions (Rode et.al, p.6 2015) and changing perception of people. In small cities, the primary role of transit is to provide mobility to the transportation-disadvantaged. This is a matter of equity more than efficiency. It reflects the view that travel is essential to human beings and that all citizens are entitled to some form of transportation service, regardless of their circumstances (Black, p.20, 1995).

Marshall (p.50, 2005) mention a conventional hierarchy between 'mobility' and 'access', these are bound together in a single, inverse relationship (Figure 2). This relation means that any street that does not fit onto this 'idealised' relationship or does not fit into the classification (Figure 3). The result is that the classification cannot represent the actual street types found on the ground. This means that not only is the classification no longer a reflection of today's aspirations, but it is not capable of representing the range of existing street types – and never was.

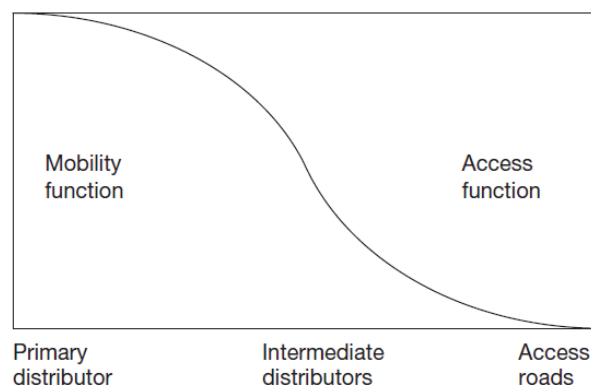


Figure 1. The classic inverse relationship between mobility and access (Marshall, p.50, 2005))

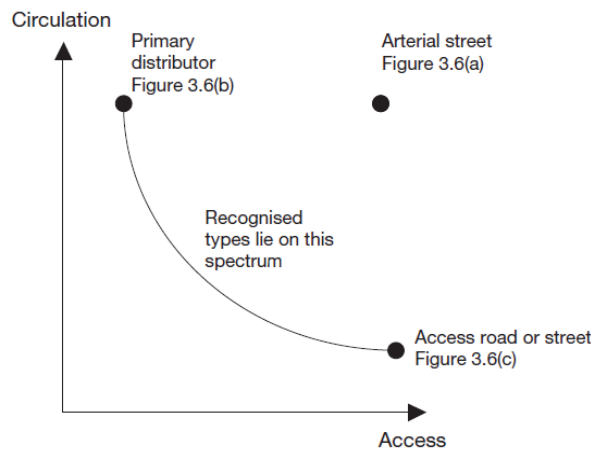


Figure 2. The conventional classification has no place for the traditional arterial Street. (Marshall, p.50, 2005)

### ***The Concepts of 'Quality of Life' and 'Liveability'***

*Finally, a renewed focus on health, wellbeing and quality of life in cities means we are rediscovering the benefits of traditional active travel modes such as walking and cycling as different modes or models in mobility. (Rode et.al, p.6, 2015)*

Quality of Life is related to human basic needs. The spatial quality of life is important in terms of generating identity of space and sustaining memory of the place. In the literature, two distinctive types of urban QoL indicators are recognized;

- **Objective indicators** measure concrete aspects of the built environment, the natural environment, economy and social domain.
- **Subjective indicators** that are connected to the individual's evaluation of objective conditions of life.

Human actions, being contemporary view of QoL in planning, can modify spatial QoL. Therefore, the spatial QoL can be; **controlled, adjusted and enhanced** by individuals through the use and management of these objective and subjective indicators.

### ***Pedestrian Movement - Walkability***

Walkable environment is a place where is a safe, secure and convenient to travel by foot (Krambeck and Shah, 2006). Walkability is regarded as the quality of pedestrian facilities, street patterns, sidewalks, roadway condition, built environment and especially urban design characters. Hutabarat (p.145, 2009) claims that the definition of pedestrian and the development of pedestrian space have big importance to understand the walkability discourse.

The Oxford Dictionary (<http://oxforddictionaries.com/definition/pedestrian>) defines pedestrian as "a person walking rather than travelling in a vehicle". Therefore, the walking activity is regarded as a mode of transport.

Likewise, walking is an activity which keeps public spaces alive, dynamic and colourful. Forsyth and Southworth (p.1, 2008) indicate crucial role of pedestrian experience in street as *"...In ignoring the pedestrian experience, the street lost its intimate scale and transparency, and became a mere service road, devoid of public life."*

Walkability quality of urban environment can be measurable. There might be many qualitative and quantitative measures to assess walkability capacity. Safety, orientation,

comfort, diversity, attractiveness, destinations and street pattern are some of these qualities. (Figure-4, Belge, p.16, 2012).

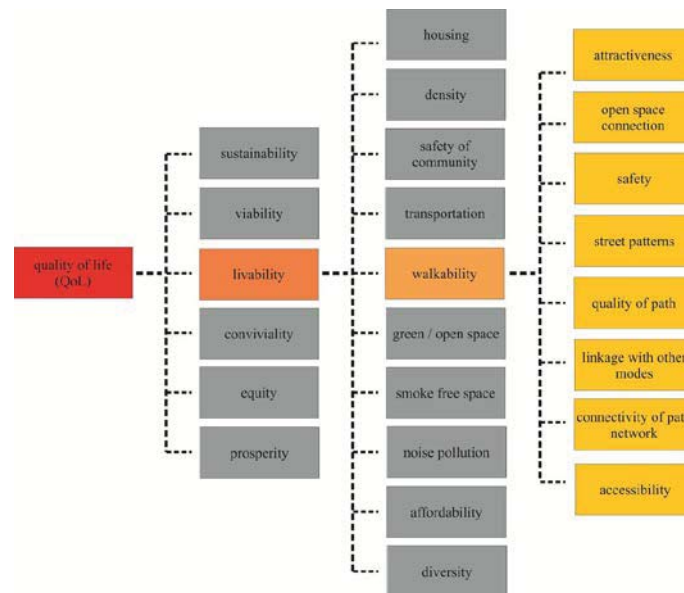


Figure 3. The evaluation of Quality of Life in terms of Walkability (Adapted from, Hancock, T., et.al. 1999, Hutabarat L.R., 2009, Lambert K, 2005 and Southworth, M., 2005 by Belge, 2012)

### General Evaluation in terms of Planning

In terms of planning, urban design is crucial to produce public space. Carmona (et al., pp.6-8, 2008) mentions three approaches in urban design as visual-artistic tradition focusing visual qualities of buildings and space, secondly social usage tradition concentrating social qualities of places and activities. Lastly, making place tradition synthesis these two approaches, which focuses on design of urban space as aesthetic and behavioural - social value? Socio-spatial approach also relates with the management and planning of urban space. Planning of public space includes coordination, regulations, maintenance and investment-financial dimensions within varying scales.

In addition to physical characteristics, space is area for both production of social and including social. Human perceive space and experience it and there is interaction between human and space as the routine of daily life. In the planning literature, the discussions of public space and space-place are changed and transformed related with embedded social and spatial features. In defined context, pedestrian could be evaluated only as a mode of transportation or a way of healthier life. However, pedestrian as not only a transportation mode, but also embedded social feature of public space would form public space. The role of pedestrian and mobility in publicness, inclusivity and accessibility of public space is not properly discussed.

### Justification

The section on justification part includes outstanding topics, concepts and theories related with public space and systematically evaluate review to understand the role of pedestrian in discussions. The role of pedestrian is investigated within the terms of city and regional planning and urban design to determine qualitative research themes.

Therefore, the term of public space is conceptualized by historical perspectives. Then, contemporary debates, critiques are evaluated by dimensions of public space as a manner

of management. In defined context, studies focusing quality in public space are reviewed. After that, pedestrian movement in public space is examined within the concepts of quality of life and liveability. Walkability and designing public space are studied as a focus for urban design approaches. Lastly, literature review is evaluated in terms of urban planning.

Therefore, instead of approaches, which see the pedestrian movement in public space is mostly discussed with space-syntax approaches or pedestrian is evaluated only as a mode of transportation with technical qualities, the study primarily focuses on quantitative measure in making public space.

## Methodology

The section briefly explains the method of proposed research based on a case study approach. The method compromises two main sections as theoretical framework and case study.

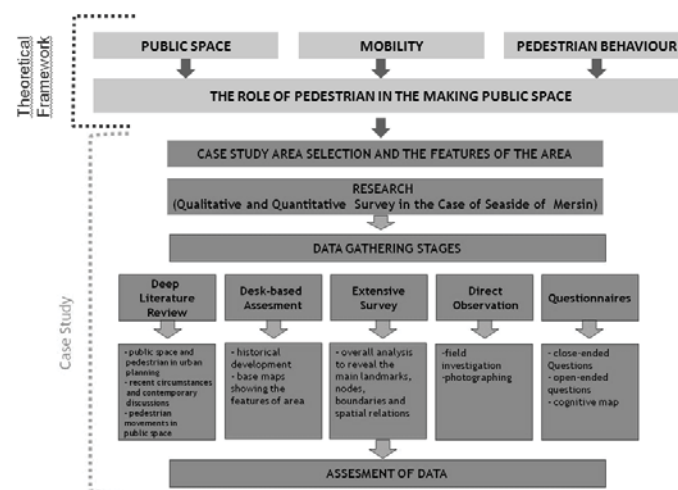


Figure 5. The flowchart indicating the method of the study

## Measures of Key Determinants

Table 1 The indicators of pedestrian behaviour and probable primary and secondary data sources (adapted from Kitazawa and Batty, 2004, Gehl 1996 cited in Carmona et al. 2008, Bauer et al., 2009, Kürkçüoğlu and Ocakçı, 2015)

ASPECT	INDICATORS	PRIMARY SOURCES	SECONDARY SOURCES
<b>Human and social factors</b>	<ul style="list-style-type: none"> <li>Personal preferences                             <ul style="list-style-type: none"> <li>Necessary activities</li> <li>Optional activities</li> <li>Social activities</li> </ul> </li> <li>Crowding</li> <li>Noise</li> <li>Other pedestrians' movements</li> <li>Safety</li> </ul>	<ul style="list-style-type: none"> <li>Field works</li> <li>Questionnaire</li> <li>Interview</li> </ul>	<ul style="list-style-type: none"> <li>Neighbourhood population</li> </ul>
<b>Built-up physical factors</b>	<ul style="list-style-type: none"> <li>Land-use</li> <li>Diversity</li> <li>Attractiveness</li> <li>Security</li> <li>Transfer points</li> </ul>	<ul style="list-style-type: none"> <li>Field works</li> <li>Questionnaire</li> <li>Interview</li> </ul>	<ul style="list-style-type: none"> <li>Development plans</li> <li>Aerial photographs and Satellite images</li> <li>Projects</li> </ul>



	<ul style="list-style-type: none"> <li>– Aesthetical quality(lightening, landscape, street pavements, ...)</li> <li>– Orientation and information boards</li> <li>– Facilities</li> <li>– Barriers</li> </ul>		
<b>Natural factors</b>	<ul style="list-style-type: none"> <li>– Topography and Slope</li> <li>– Sun, wind, rain, etc,</li> <li>– Natural landscape and vista</li> </ul>	<ul style="list-style-type: none"> <li>– Field works</li> </ul>	<ul style="list-style-type: none"> <li>– Meteorological data</li> <li>– Base maps</li> </ul>
<b>Time</b>	<ul style="list-style-type: none"> <li>– Hour, Day, Week, Season</li> </ul>	<ul style="list-style-type: none"> <li>– Field works</li> </ul>	

Table 2. The indicators of mobility and probable primary and secondary data sources (adapted from Marshall, 1978, Strogmeier, 2016, Kallerman, 2016, [http://www.civitas.eu/sites/default/files/documents/rye\\_session\\_8\\_civ\\_forum\\_2015\\_capital\\_ag5\\_v3.pdf](http://www.civitas.eu/sites/default/files/documents/rye_session_8_civ_forum_2015_capital_ag5_v3.pdf) and Texas Transportation Institute The Texas A&M University System <http://mobility.tamu.edu>)

ASPECT	INDICATORS	PRIMARY SOURCES	SECONDARY SOURCES
<b>Accessibility</b>	<ul style="list-style-type: none"> <li>– Availability to alternative transportation modes.</li> <li>– Presence, location, continuity and obstruction of sidewalks</li> <li>– Sidewalk width and condition</li> <li>– Presence, location continuity and obstruction of bike lane, condition of bike lane</li> <li>– Parking and on street parking</li> <li>– Orientation</li> <li>– Public transport</li> </ul>	<ul style="list-style-type: none"> <li>– Field works</li> <li>– Questionnaire</li> <li>– Interview</li> </ul>	
<b>Extensive area</b>	<ul style="list-style-type: none"> <li>– Land use (mixed used, commercial, residential, public places)</li> <li>– Diversity</li> </ul>	<ul style="list-style-type: none"> <li>– Field works</li> </ul>	<ul style="list-style-type: none"> <li>– Development plans, reports</li> <li>– Base maps and planning analysis of the Municipalities</li> </ul>
<b>Public Recreational facilities</b>	<ul style="list-style-type: none"> <li>– Availability of facilities (indoor fitness facility, Park, Playground, Outdoor pool, Beach, Sports playing field, basketball court, tennis court (park or school), Marina</li> <li>– Availability of equipment (playground</li> </ul>	<ul style="list-style-type: none"> <li>– Field works</li> </ul>	<ul style="list-style-type: none"> <li>– Meteorological data</li> <li>– Base maps</li> </ul>

	equipment, sports equipment, etc.)		
<b>Services and amenities</b>	<ul style="list-style-type: none"> <li>– Service amenities</li> <li>– Equipment rental stand</li> <li>– Sports stands/seating</li> <li>– Picnic tables</li> <li>– Water fountains</li> <li>– Restrooms</li> <li>– Vending machines</li> <li>– Trash bins</li> </ul>	– Field works	–
<b>Aesthetic quality</b>	<ul style="list-style-type: none"> <li>– Attractive features (architectural design, building variety, vegetation, signage)</li> <li>– Comfort features (shades, trees, benches or other type of amenities)</li> </ul>	– Field works	–
<b>Pollution</b>	<ul style="list-style-type: none"> <li>– Air pollution (diesel fumes, ...)</li> <li>– Noise pollution (vehicle, construction ...)</li> </ul>	–	– Measurements

### ***Making public space***

Varying factors of **pedestrian behaviour** and **mobility** for **making public space**. Whether public space or not? ...according to;

- number of pedestrian.
- frequency of use.
- periods of use.
- reason of use.

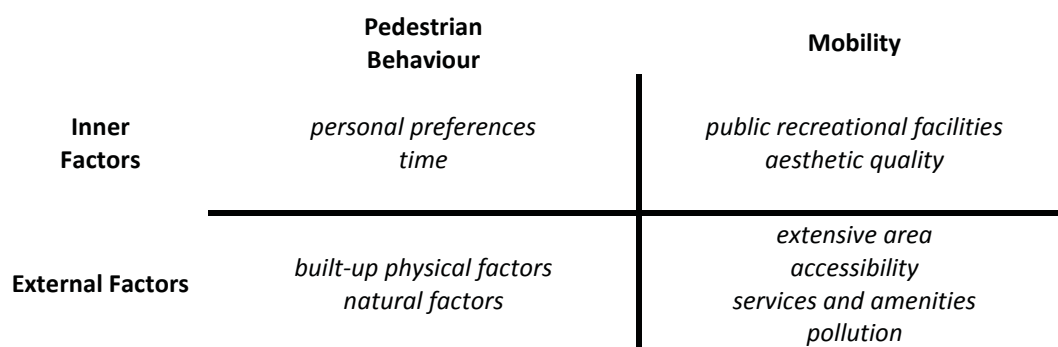


Figure 6. The level of factors in making public space

### **Case Study; Seaside of Mersin as a Recreational Public Space and a Pedestrian Focus**

Mersin has been expanded along the Mediterranean coast since its establishments, but the macroform of the city has considerably changed in the last 50 years. The city recently lays approximately 30 km from east to west. The main aim of research is to observe the seaside

as a pedestrian and then propose means to improve seaside as a public space. The study aims to affirm pedestrian not only as a mode of transportation in urban planning but also to make places for themselves.

In defined context, the study aims to evaluate the evolution of public space through history, especially in Turkey and the role of pedestrian as a dynamic character in public space during the development of public space to gain characteristics or identity. Out of vehicular traffic or mass transportation modes, each person with varying characteristics and goals is a pedestrian, who uses public space while shape public space.

In Turkey, the utilizations and image of the public spaces are changing with the local policies and in the case of Mersin; this situation is done by ignoring urban design criteria. Consequently, the research looks for characteristics of the seaside of Mersin as a recreational public space and a pedestrian focus in terms of openness/accessibility and accountability determined by varying features. Recent coastline of Mersin has been formed by different filling operations since the beginning of 20th century. From the centre of Mersin to western residential district, a huge land has been filled to construct traffic roads, harbours, marines or recreational sides. Today's, the most of filling area are used for recreational facilities. However, while some areas are efficiently used, some zones could not be used or ignored by pedestrians. It is a planning and urban design problem for the publicness of seaside. Moreover, the setting of seaside has crucial effects of uses. Therefore, not only design of park area but also its relationship with inner areas and relation with waterfront should be evaluated (Figure 7).



Figure 7. The limits and uses of the case study area

The seaside of Mersin, as a filled platform, defines a kind of facade of the city up to the sea. It is broken by the rapid and constant circulation on the coastline. So its mission as a park is uncertain. Recent constructions, parking areas, gastronomic facilities, the Marinas, culture centres, administrative units or kindergartens, sport facilities for walking or running or just recreational activities especially does not raise the expected level. On the contrary, shopping malls and centres succeeded in turning the coastline into the notorious place of the city. In defined context, how pedestrian movement would be efficiently used to transform seaside into public space and how the publicness of seaside could be evaluated in terms of accessibility, openness and design quality?

Infill developments and huge recreational areas along the seaside caused to lose the characteristic of Mersin as a Mediterranean Port City. Nowadays, high density, development pressure and implicitly vehicular traffic in the city disturb pedestrian movements in relation with lack of liveable spaces. Naturally, citizens tend to choose more liveable and

comfortable areas, so commercial dynamics and potential move to shopping malls. In addition high-rise apartments and vehicular traffic are lying parallel to seaside. Thus, interconnections between inner sides and the sea are interrupted. Moreover, recreational area that is located on the infill area does not include pedestrian axis from inner sides into seaside. Especially car parking creates barriers for north-south directed movements. Furthermore, negative spaces and lack of transportation facilities cause losses in public spaces networks, so publicness of Mersin seaside is harmfully affected (Figure 8).

As sum, there are too many oversized areas and concrete uses in recreational spaces. Sculptures, abstract forms, sometimes over-detailed figures, replicas of ancient or modern structures or heroes from cartoons create a mess of design in seaside. On the other hand, although an ordinary and routine relation is designed between seaside and recreational activities, some areas in seaside are densely used by varying social groups with changing income, age, gender, etc. while there are some loose spaces in same context.

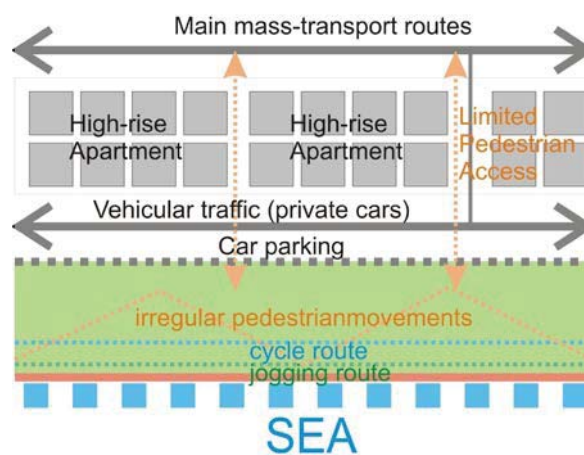


Figure 8. Current relations and movements in case study areas

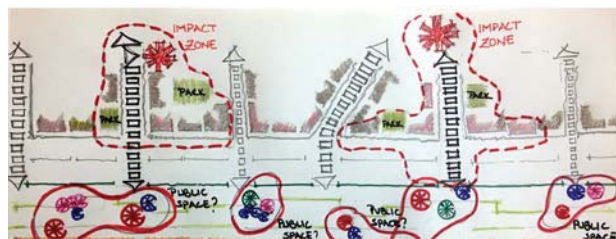


Figure 9. Tentative sub-zones

Not only recreational facilities or aesthetic quality in case study area, but also impact zones, foci, characteristics of built-up area and different land use patterns at the northern side of Adnan Menderes Boulevard are going to be effective to define tentative sub-zones in case study area.

In defined context, in the research, the term of accessibility means access to case study area. In other words, accessibility is relation between the city and case study area. On the other hand, the term of mobility is related with the inner aspects of the site.

## References

Akkar, M. (2005) The changing 'publicness' of contemporary public spaces: A case study of the Grey's Monument Area, Newcastle upon Tyne. *Urban Design International*. 10: 95-113.

- Akkar, M. and Memlük O.N. (2015) More inclusive than before: The tale of a historic urban park in Ankara, Turkey, *Urban Design International*. 20: 195-221.
- Bauer, D., Brandle N., Seer S., Ray M., Kitazawa, K. (2009) *Measurement of Pedestrian Movements: A Comparative Study on Various Existing Systems, Pedestrian Behavior: Models, Data Collection And Applications* (Ed. Timmermans, H.), Emerald, UK, pp.325-344.
- Belge, Z.S. (2012) *Increasing Walkability Capacity of Historic City Centres: the Case of Mersin*, unpublished Master Thesis, METU, Ankara, <http://etd.lib.metu.edu.tr/upload/12614768/index.pdf>
- Black, A. (1995) *Urban mass transportation planning*, McGraw-Hill, USA
- Carmona M., De Magalhaes C. and Hammond L. (2008) *Public Space, The Management Dimension*, Routledge.
- Carmona, M., Heath, T., Oc, T., Tiesdell, S. (2010) *Public Places – Urban Spaces*, Architectural Press, Oxford.
- Carr, S., Francis, M., Rivlin, L.G. and Stone, A.M. (1992) *Public Space*. Cambridge: Cambridge, University Press.
- Forsyth, A., Southworth, M. (2008) Guest Editorial: Cities Afoot—Pedestrians, Walkability and Urban Design, *Journal of Urban Design* 13(1) 1-3.
- Gehl, J. (1987) *The Life between Buildings*. New York: Van Nostrand Reinhold.
- Gehl, J., Gemzøe, L. (1996) *Public Spaces - Public Life*, The Danish Architectural Press, Copenhagen.
- Hutabarat Lo, R. (2009) Walkability: What is it? *Journal of Urbanism* 2(2) July 145-166.
- Kallerman, N. (2016) *Detailed planning through the eyes of sustainability Mobility, Green*, Nils Kallerman, Umeå University Master thesis in Human Geography Department of Geography and Economic History Master Program in Spatial Planning and Development.
- Kitazawa, K., Batty, M. (2004) "Pedestrian Behaviour Modelling: An Application to Retail Movements Using a Genetic Algorithm" *Developments in Design & Decision Support Systems in Architecture and Urban Planning* (edited by J.P. van Leeuwen and H.J.P. Timmermans), Eindhoven University of Technology, Eindhoven.
- Krambeck, H., and Shah, J. (2006) *The Global Walkability Index: Talk the Walk and Walk the Talk* [[http://cleanairinitiative.org/portal/system/files/60499\\_paper.pdf](http://cleanairinitiative.org/portal/system/files/60499_paper.pdf)] Accessed in 29.08.2014).
- Kristensen, J. P., & Marshall, S. (1999). *Mobility Management to Reduce Travel: The Case of Aalborg*. *Built Environment* (1978), 25(2), 138–150. Retrieved from <http://www.jstor.org/stable/23288533>
- Kostoff, S., (1985). *A History of Architecture: Settings and Rituals*. New York: Oxford University Press
- Kürkçüoğlu, E., Ocakçı, M. (2015) *A Perceptual Behavior Study on Spatial Orientation in Urban Fabric: Kadıköy Bazaar District*. *Megaron.*, 10(3): 365-388
- Lefebvre, H. (2014) *Mekânın Üretimi*, (Ed.) Ergüden I., İstanbul
- Marshall, S. (2005) *Streets and patterns*. Routledge.
- Montgomery, J. (1998) *Making a City: Urbanity, Vitality and Urban Design*, *Journal of Urban Design*, 3: 1, 93-116
- Resuloğlu, Ç. (2011) *The Tunalı Hilmi Avenue, 1950s-1980s: The Formation of a Public Place in Ankara*, unpublished Doctorate Thesis in the Graduate School of Social Sciences of Middle East Technical University, Ankara.
- Rode, Philipp; Christian Hoffmann; Jens Kandt; Duncan Smith; and Andreas Graff (2015) *Toward New Urban Mobility: The case of London and Berlin*. Peter Griffiths (ed). LSE Cities/InnoZ. London School of Economics and Political Science: London
- Strogmeier, F. (2016) *Barriers and their Influence on the Mobility Behavior of Elder Pedestrians in Urban Areas: Challenges and Best Practice for Walkability in the City of Vienna*.
- Tekeli, İ. (2008) *Bir Plancı/Araştırmacının Yöntem ve Ötesine İlişkin Arayışları*, *Felsefe dergisi*, Sayı 6, s.1-25, <http://www.flfsdergisi.com/sayi6/1-25.pdf>
- Wycherley R.E. (1993). *Antik Çağda Kentler Nasıl Kuruldu, Arkeoloji ve Sanat Yayınları*.



*Chapter 5:*  
*Building simulation and Building Information*  
*Modeling (BIM)*

# Visualization techniques for heterogeneous and multidimensional simulated building performance data sets

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**Abstract:** The architecture, environment and construction industry is facing, on the one hand, ambitious environmental regulations for low carbon and net zero energy buildings, and on the other hand, the emergence of new techniques such as parametric assessment and cloud computing. As a result, there is a dramatic increase of performance analysis and collected data during the building design phase. However, previous research highlighted major weaknesses of current building performance simulation -*BPS*- software regarding its ability to represent and explore input and output data, to interact with it, and to extract valuable data patterns and analyses. Therefore, this research aims to identify suitable visualization techniques that might increase the usability and the knowledge extracted from building simulation dataset.

To that end, an interdisciplinary approach has been set up. First, a literature review allowed to characterize the specificities of *BPS* dataset, namely their heterogeneous nature -discrete, ordinal, categorical, and continuous-, their different correlation levels and their medium size. Second, key tasks that should be performed by *BPS* tools to support the design process are identified: exploration, solutions generation and evaluation. Then, two data visualization techniques that accept the *BPS* dataset specificities and that enable to perform these key tasks were selected within the information visualization research field: Decision Tree and Parallel Coordinates. Third, these techniques were applied to an extensive *BPS* dataset, generated from a series of parametric building simulations based on a high-performance building to be, called the smart living building. Finally, a qualitative comparison between the selected visualization techniques was conducted so as to reveal their strengths and weaknesses. This comparison highlights Parallel Coordinates as the most promising approach.

**Keywords:** building performance simulation tools, datasets, data visualization, data exploration.

## Introduction

The built environment is a major greenhouse gas contributor with 33% of the world emissions (UNEP 2009a, 2009b). Recent international agreements such as the UN Conference on Climate Change in Paris in 2015 (UNFCCC 2015) leads each stakeholder to implement and strengthen their local environmental regulations all over the next century. Therefore, the complexity of these regulations is continually rising, as their targets are more and more ambitious. For instance, the future 2020 European Union directive (EU - EPBD 2010) will require every building to generate more energy than it will consume, that is to say to reach the Net Zero Energy Building -*NZEB*- level (Sartori et al. 2012). Some countries like France are already working to integrate energy and carbon lifecycle targets in their future regulations (Plan Bâtiment Durable 2014). By doing so, the Architecture, Engineering and Construction industry will have to assess every process and material involved into a building project, and

not only the ones that consume energy during the building operational phase, as was the case so far.

In order to support all these new regulations, the Building Performance Simulation - *BPS*- research and development field is playing a key role, by developing new methods and software enabling energy and lifecycle performance to be taken into consideration as early as possible in the design process. During the last decade, many improvements in *BPS* tools followed a new trend: developing workflows by coupling energy simulation algorithms with other techniques (Østergård et al. 2016). The aim is to support the design process based on *BPS* datasets, generated parametrically from a baseline architectural model. Researchers start to consider the dataset exploration itself as a powerful decision making process. A new proactive usage of *BPS* tools is possible, with the fast creation of design alternatives and their performance assessment and exploration with data visualization techniques -*DVT*-. The first promising results have been highlighted in previous research (Jusselme et al. 2016, Miyamoto et al. 2015, Naboni et al. 2013).

However, at the same time, the assessment of thousands of variants increases the complexity of data interpretation. A study based on 28 interviews of building performance optimization experts (Attia et al. 2013) highlights that 75% of them do not have a proper graphical user interface -*GUI*- to process the assessment results, visualize patterns and explore input and output data. Most of the experts develop their own custom script to interpret results, with basic visualization techniques such as Pareto front, scatter plot, line graph, bar chart and time series. From the interviewee point of view, optimization techniques are mostly used to explore the design space of alternative solutions, which is in fact more relevant than finding the best one. Despite this exploration emphasis, one can notice that in Attia's paper, no cited *DVT* are dynamic as they do not allow the user to interact with the *GUI* in a proactive way. The purpose of the present paper is specifically to bridge different research fields that have not really been connected so far: the *BPS* engineering and the data visualization domain. Which would be the suitable *DVT* that should be integrated by *BPS* tools in order to support a data driven design?

The first section will be dedicated to the characterisation of *BPS* datasets. What are their main characteristics? Thanks to this knowledge, requirements will be set up to qualify how *DVT* might be suitable to explore this data. In the second section, *DVT* are highlighted via a literature review. These techniques are ranked according to their ability to fulfil the requirements defined in the first section. In the third section, a case study allows the implementation of the two most promising techniques. Finally, the last section compares the strengths and weaknesses of the two implemented techniques.

## **Requirements for data visualization techniques**

*DVT* address a large spectrum of data, but their usability is highly dependent on the characteristics of the data. Thus, the purpose of this section is first to define the *BPS* dataset specificities. Secondly, tasks that should be performed by decision making tool to support the design process are identified. Datasets specificities and tasks will be used as requirements (*RX*) for the data visualization techniques selection. They are identified from (*R1*) to (*R8*) within this section.

### ***Dataset characteristics***

*BPS* datasets are the result of simulations that estimate the output value for a given combination of dimensions. They usually include ten to twenty dimensions (Jusselme et al.

2016, Miyamoto et al. 2015) and several output values representing the performance of each design alternative.

A literature review of techniques that allowed to create *BPS* datasets has been done. Among these techniques, one can cite approaches involving parametric analyses (Hollberg and Ruth 2016, Jusselme et al. 2016, Lolli et al. 2017), those dealing with sensitivity and uncertainty analysis (Heeren et al. 2015, Hopfe and Hensen 2011, Tian 2013), methods that include a multivariate regression (Catalina et al. 2013, Hygh et al. 2012), and those that include meta-modelling (Eisenhower et al. 2012, Manfren et al. 2013).

Based on their method and findings, one can make the following points:

- *BPS* datasets are characterized by input values defining building parameters that are chosen to feed the workflow, and output values, which are the *BPS* assessment results. Inputs are discrete values composed by ordinal -e.g. the Thermal transmittance:  $U=1 \text{ W/m}^2\text{K}$ - and categorical data -e.g. the type of insulation: Rockwool-. Outputs are continuous -e.g. the  $\text{CO}_2$  emissions:  $10 \text{ Kg CO}_{2\text{eq}}/\text{m}^2\cdot\text{y}$ -, discrete and categorical data -e.g. Thermal comfort: Good-.
- Inputs and outputs can be correlated -e.g. photovoltaic panel surface and energy performance- and non-correlated -e.g. photovoltaic panel surface and heating demand-.
- The datasets have a medium size: they are too big to be understandable with traditional graphical tools, but not enough to be associated with the “big data”, which deals with terabytes of information. Datasets coming from *BPS* are generally sized from hundreds to hundreds of thousands -100k- of design alternatives. Indeed, in Naboni’s research (Naboni et al. 2013), a parametric analysis involving 8 parameters induced the calculation of 221’184 design alternatives.

As a conclusion, the main characteristics of *BPS* datasets are their heterogeneous nature (*R1*), their different correlation levels (*R2*) and their medium size (*R3*).

### **Tasks required by *BPS* tool users**

In early design stages, designers do not require accurate simulation results, but rather “an understanding of the relative effect on performance due to changes in design alternatives” (Bambardekar and Poerschke 2009). The priority for the designer is to get “a qualitative and overall design direction”. Such a tool should allow the visual exploration and assessment of the potential solutions’ space, and should be able to generate new solutions if required. A key remaining challenge is to focus the attention of the designer on the important parameters and to integrate simulation feedback into his design process (Ibarra and Reinhart 2009, Reinhart et al. 2012). According to Huot, numerous studies about design process highlighted three main activities: exploration, solution generation and evaluation (Huot 2005). An appropriate decision-making tool should integrate these tasks, allowing for a smooth user-machine interaction.

#### **Exploration**

Exploration brings together the prior learning of the designer and the external data that he will have to gather and assess on the subject. Exploration allows the designer to better understand the constrained problems -correlations, patterns- by tuning parameters.

Here is a more detailed list of tasks that the designer should be able to execute:

- Dataset overview (*R4*): being able to get an overview on the whole dataset, with all its dimensions at a glance.
- Impact of parameters (*R5*): identifying the parameters with the highest impacts on the assessment results.

- Similarity task (*R6*): identifying the strength of correlations between input and output, patterns and clusters.
- Frequency task (*R7*): identifying the most represented parameter values.

### *Solutions generation*

Generating a solution is defined as filtering the database in order to keep only one design alternative that complies with a set of constraints. As previously exposed, the designer should be able to take decisions based on feedback from BPS software, rather than his prior experience (Bambardekar and Poerschke 2009). These solutions can then be compared and the best one is selected, according to the designer's own preferences and other criteria such as norms.

- Filtering task (*R8*): being able to set constraints -e.g. norms, cost, preferences- based on parameter values, in order to filter out the undesired alternatives.

### *Evaluation*

The third step consists in selecting the most convenient solution among the solutions space. It is up to the designer to assess the solutions, giving more importance to some criteria. The evaluation is permanent during the creative process, often raising the need to take the first two steps over again.

- Filtering task (*R8*): determine a set of parameter values that define a building design, i.e. make a final decision.

### **Data visualization techniques specifications**

Multidimensional *DVT* should allow the comparison of the quality of several solutions. They should also fit the designer's creative process. Choosing a set of parameters defining a building can be seen as an under-constrained configuration task: no optimal solution exists, and the final choice depends on both qualitative -aesthetic preference, comfort- and quantitative criteria -performance threshold-. Such tasks involve both the human and the machine: the user is actively involved in the decision-making process and needs to choose among a set of acceptable solutions. A constraint is a condition that has to be met for the solution to be valid. It is usually a numerical value representing cost, or performance.

In summary, thanks to the dataset characteristics and to the user needs previously explored, we were able to set the following key requirements for visualization techniques applicable to *BPS* multidimensional dataset: *R1* Dataset size <100k; *R3* Data type; *R4* Overview; *R5* Impact; *R2*, *R6* Similarity/Correlations; *R7* Frequency; *R8* Filtering. These specifications will be used in the next chapter in order to qualify different *DVT*.

### **Overview and selection of data visualization techniques**

This section explores mainly bibliographic references of datasets which are not in the field of architecture or building performance, but still relevant for this study. Data visualization is a powerful way to provide the user with insights and useful information about very complex problems (Agrawal et al. 2006). Adding interaction techniques to such displays allows the user to explore the dataset and solve problems in real time. Particular attention should be taken when establishing a compromise between the amount of information, simplicity and accuracy, especially in the case of multivariate *DVT* (Chan 2006). As opposed to fully automated systems, Mixed Initiative Systems -*MIS*- involve the user in the problem resolution process [Horvitz 1999]. *MIS* are useful in optimization problem solving, since "*non-expert users [...] prefer an incremental and interactive procedure to build solutions rather than a completely automated*

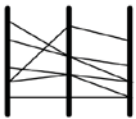

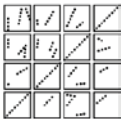
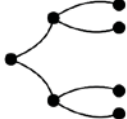
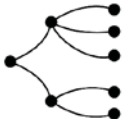



approach." (Cortellessa 2006). *DVTs* play an important role in Mixed Initiative user interfaces, as they give the user visual cues and information, reducing his cognitive load (Pu and Lalanne 2002).

### A first overview

A selection of *DVT* applicable to multivariate and multidimensional data has been established by means of a literature review. Table 1 summarizes the potential of each technique to fulfil the requirements that have been listed in the previous section -R1-8-. A qualitative ranking is proposed by rating each *DVT* according to its potential to fulfil the requirements: "+" is associated with a high potential to meet the requirement and is credited with 2 points, "+" means that the requirement may be hard but is not impossible to meet, and credited with 1 point. "∅" means that the *DVT* cannot fulfil the requirement, and is credited with -1 point. At the end, each *DVT* is ranked according to the resulting sum of all individual scores.

Table 1. A comparison of data visualization techniques for Building Performance Simulation dataset.  
Scoring: +=easy to reach (2pts); -= hard to reach (1pts); ∅: impossible to reach (-1pts)

	Parallel Coordinates 	Parallel Sets 	Scatterplot Matrix 	Decision Tree 	Dendrogram 	Force Directed 
Requirements	(Davies 2017a)	(Davies 2017b)	(Bostock 2017a)	(Schumacher 2017)	(Bostock 2017b)	(Bostock 2017c)
R1 Size <100k	+	+	+	+	-	-
R3. Data type	+	∅	-	+	+	+
R4 Overview	+	+	-	-	-	-
R5 Impact	-	-	-	+	-	-
R2-6 Similarity	-	-	+	-	-	-
R7 Frequency	+	+	-	-	-	-
R8 Filtering	+	+	+	-	-	-
Score (points)	12	9	10	10	8	8

With a few visual enhancements -alpha blending, jittering, frequency encoding-, the first four *DVTs* can handle 100'000 design alternatives. Parallel Coordinates and Parallel Sets allow the assessment of the correlation between adjacent dimensions, i.e. they require the user to reorder the dimensions if non-adjacent. While both of these visualization methods are the best at assessing the frequency of a given parameter value amongst the one selected in Table 1, there is a significant drawback with Parallel Sets related to their inability to handle continuous parameters, making them useless for a *BPS* dataset. In contrast, the Scatterplot Matrix is designed for continuous values, and representing categorical dimensions results in heavy over-plotting. In this case, jittering and alpha blending can improve the visualization to some extent. However, the number of dimensions should stay under 10 to remain readable.

The Decision Tree is, on the other hand, the most suitable to show the impact of parameters. Dendrogram and Force directed do not scale well with the dataset size, as they need to represent each design alternative as a node, and thus require a lot of space in order to display all the data. Decision Tree, Dendrogram and Force directed are not appropriate to compare the similarity between dimensions, but are a good way to find clusters of design

alternatives. However, they do not implement a filtering interaction, and thus require the use of link and brush interactions with an external filtering method.

Harrison et al. recently expanded on previous work by studying the perception of correlations in Parallel Coordinates compared with eight other visualization techniques: scatterplots, stacked areas, stacked lines, stacked bars, donuts, radar charts, line plots, and ordered line plots (Harrison et al. 2014). 1687 participants took part in the test, using a crowdsourcing platform. The task was to judge the strengths of different correlations. Their results are consistent with the work from Li et al. (Li et al. 2008), in which scatterplots depict correlations better than Parallel Coordinates.

In the end, considering the score, Parallel Coordinates seems to be the most suitable for the visualization of a *BPS* dataset. In second position, the choice is directed towards the Decision Tree, as it can handle well more than 10 mixed categorical and continuous dimensions. The next sections give a deeper description of the most promising techniques according to the scoring of Table 1, and a qualitative analysis regarding the tasks they should help complete.

### **Parallel Coordinates**

Parallel Coordinates (Inselberg and Dimsdale 1990) are the most popular visualization method to represent multivariate multidimensional data. They are applied to a large set of multidimensional problems (Rodriguez and Nancy 2016) in many fields -e.g. life sciences, engineering and finance- (Heinrich and Weiskopf 2013). In practice, such datasets contain up to some 10-15 dimensions (Kosara et al. 2006). Moustafa (Moustafa 2011) states that Parallel Coordinates are becoming an *"essential tool for visualizing hyper-dimensional numerical data from almost all real life applications [...]"*.

They use a parallel layout for axes: the horizontal spatial position is used to separate axes, and the vertical spatial position is used to express the value along each aligned axis. Each data item is depicted as a polyline intersecting all the axes. Parallel Coordinates allow the user to set constraints: filtering the dataset is done by selecting a range of values for each parameter -i.e. brushing-. Parallel Coordinates can be used to select a set of parameter values that define a building design and to assess whether the solution is valid, i.e. the output values from the output axis are below a given threshold -e.g. price, comfort, or energy consumption-.

Parallel Coordinates can be displayed in other layouts: vertical, and star layouts. The star layout is better when there are inliers in the data: *"homogenous records [...] appear as distinct star shape"* (Moustafa 2011). A connecting line between two entities shows the relationship between two axes in an explicit way: this is especially pertinent to spot trends (Munzner and Maguire 2015) and can be used to identify an individual data item.

Parallel Coordinates are well suited for the type of tasks that we mentioned in the previous section. Without the use of any enhancement method, the number of items is limited to a few hundreds. 100'000 items can be represented by adding clutter reduction methods such as jittering or alpha blending to the polylines. Parallel Coordinates can assist in the identification of highly discriminant dimensions (Moustafa 2011). Parallel Coordinates allow the easy assessment of the strength of correlations. The lines connecting the dimensions enable the identification of correlated dimensions: a high positive correlation is characterized by a set of parallel segments, while a negative correlation is characterized by a set of segments crossing over at a single point. However, this only allows pairwise comparison between neighbouring axes. Visible patterns depend on the ordering of axes; this requires

the user to test all possible configurations of axes, which becomes time consuming as the number of dimension increases.

Parallel Coordinates are helpful in data mining tasks such as the identification of clusters and the exploration of class properties. They allow the user to identify the most represented parameter values. For the larger datasets, jittering and alpha blending can be used to restore the frequency information.

### **Decision tree**

Decision trees are a great decision support tool. Rather than being a true exploratory tool, they make it possible to "[...] *break down a complex decision-making process into a collection of simpler decisions, thus providing a solution which is often easier to interpret.*" (Safavian and Landgrebe 1990). The first step in the construction of a decision tree is a learning phase. It is initiated taking a set of vectors as input, each belonging to a known class: several machine-learning algorithms will then help to determine which attributes best divide the data between the classes, based on impurity measures. As an example, the C4.5 algorithm is an Information Gain algorithm. It selects the parameters that best split the target class into the purest possible children nodes. In other words, the parameters with the highest scores are the ones that best divide the samples between two classes. It places the most important parameters closer to the root of the tree. By adding collapsible nodes to the decision tree, only the most important parameters are initially shown to the user. In order to get a full set of parameter values, he has to click on the children nodes until he reaches a leaf.

Tree nodes can be visually enhanced with two types of visual cues: a colour coding - green or red- can, for example, show the ratio of each class included in the leaves represented by the node. The size of a node can indicate the amount of design alternatives included in the subset.

The decision tree is not highly scalable in terms of dimensionality. As stated by (van den Elzen and van Wijk 2011), "*For a decision tree to be understandable, its complexity should be low, which can be measured by the following metrics: (1) the total number of nodes; (2) total number of leaves; (3) tree depth; (4) number of attributes used*". Small trees containing fewer attributes are therefore preferred. This method imposes a ranking of parameters, and is thus optimal for assessing the impact of parameters on performance. Each node represents a parameter value, and the depth in the tree depends on the impact, allowing the user to quickly detect the most important parameters. The decision tree only shows the strength of the relationship between the class and the parameters. There is no relationship between the rate of correlation of two attributes and their position in the tree.

### **The smart living building as a case study**

The previous chapter allowed us to select two *DVT* that look promising according to our understanding of the literature. Here, the purpose is to apply these *DVT* to the dataset of a case study in order to analyse their advantages and drawbacks in a real-like situation.

The dataset that has been chosen was generated in the frame of the smart living building, which is currently under design. This building will be built by 2021 in Fribourg, Switzerland. Its aim is to achieve the 2050 goals of the 2000-watt society vision (Jochem et al. 2004). In order to guide designers towards these performance targets, a new decision making method has been developed (Jusselme et al. 2016), coupling parametric energy analysis, lifecycle assessment and sensitivity analysis. In this paper, a dataset of 25'000 design alternatives has been created using the same workflow, and a lifecycle analysis has been

performed on each, in order to quantify their Global Warming Potential -GWP- impact. As a result, the dataset encompasses the description of the 25'000 design alternatives with 17 parameters, e.g. window to wall ratio, windows properties, insulation level, photovoltaic power, HVAC system, structure type and so on. According to the Swiss norm (SIA 2011), the objective that the building has to achieve is a footprint below 12,6 Kg CO<sub>2eq</sub>/m<sup>2</sup>·year.

We implemented the two visualization prototypes presented below using the client-side web technology stack: HTML, CSS, SVG and Javascript. Since we planned to test the visualizations with several datasets, we needed a flexible approach.

Here is a summary of our requirements:

- being able to switch between several datasets.
- being able to add visual encodings to a visualization method.
- being able to handle large datasets without compromising the user experience.
- implement several interaction methods such as clicks and brushing.

To represent the data we chose the D3 Javascript library (Bostock 2017d), since it is widely used, provides a good documentation, and meets all the above requirements.

### **Implementation of the Parallel Coordinates**

According to the literature review, a few visual enhancements were added: jittering reduces over-plotting, and allows the increase of the visual perception of distribution for each parameter. We added a colour coding: each polyline is coloured according to its compliance to the target. In the example, polylines are coloured in green if their GWP is below 12.6 Kg CO<sub>2eq</sub>/m<sup>2</sup>·year, red if above the target. Brushing interaction makes it possible to filter the dataset by selecting a range of values for a given parameter. The user is able to reorder the axes in order to assess the correlation between specific dimensions.

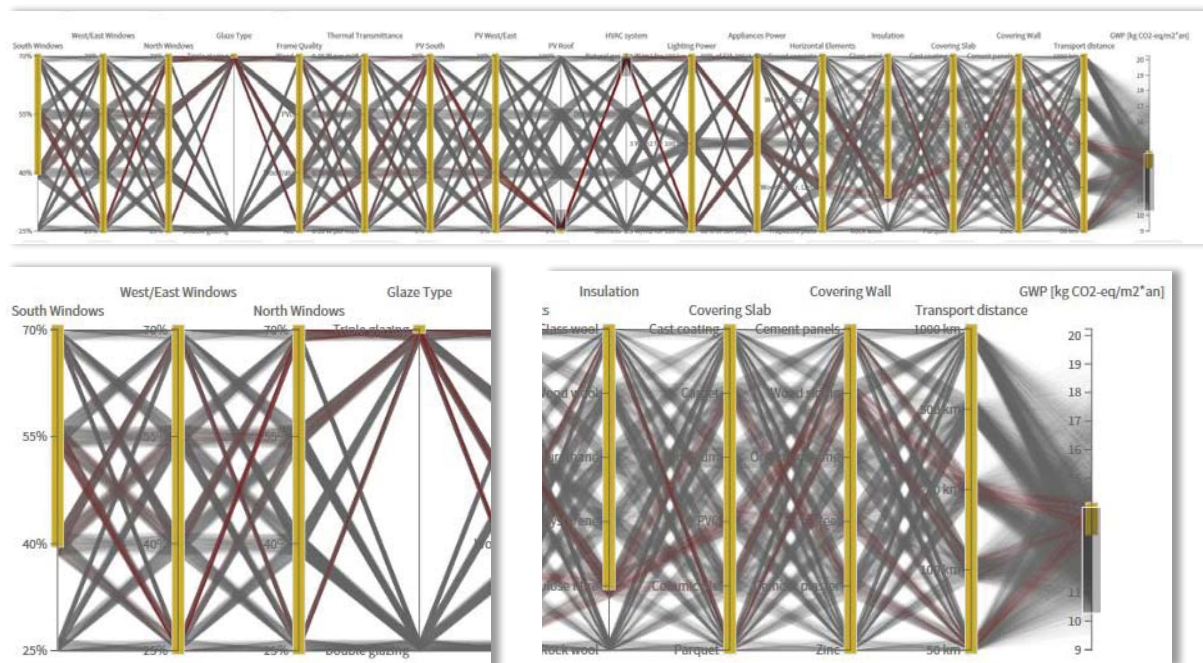


Figure 1. Visualization of the smart living building dataset with Parallel Coordinates (on the top), zoom on input parameters (bottom left) and zoom on output performance indicator: Global Warming Potential (GWP, bottom right).

## Implementation of the Decision Tree

In order to represent our dataset as a Decision Tree, we first had to compute it with the C4.5 algorithm, using a modified version of LearningJS (Yandong 2017). The Decision Tree data was stored as a JSON file. The user is able to click on a node in order to reveal its children nodes, until he reaches a leaf. A leaf represents a completely homogenous set of design alternatives: it contains only valid, or non-valid design alternatives. Nodes are scaled according to the number of design alternatives they represent. Each node is coloured according to the most represented class inside it: it is green if it contains mostly valid design alternatives, red if it contains mostly non-valid design alternatives.

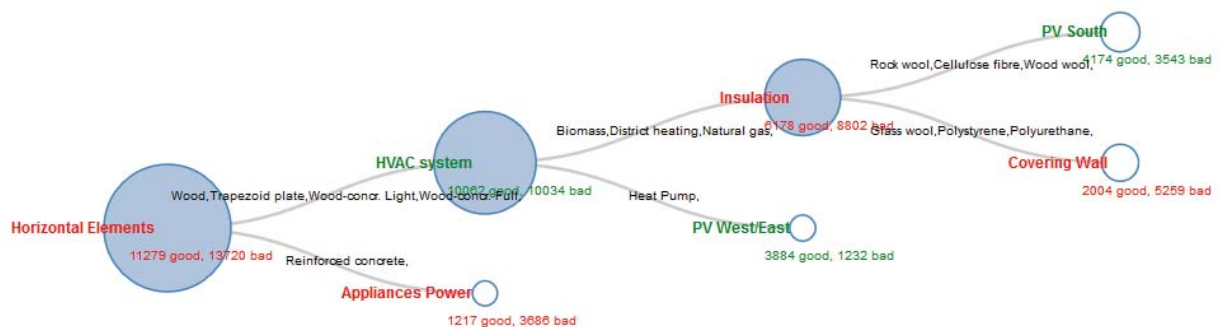


Figure 2. Visualization of the smart living building data set with a Decision Tree.

## Qualitative comparison

In this section, we perform a -non-quantitative- comparative analysis of the two most promising *DVTs* for our use case, namely the Parallel Coordinates plot and the Decision Tree. First, both methods can handle a medium-sized dataset. The Decision Tree is more scalable since it only represents aggregates of design alternatives. On its part, the Parallel Coordinates plot requires specific clutter reduction techniques -jittering, alpha blending- in order to increase its readability.

Both methods can represent mixed categorical and continuous dimensions. The number of dimensions is more limited with the Decision Tree, since a large number will inevitably increase the depth of the tree, and thus its complexity. Discrepancies in the user's mental model can appear when the dimensions include several types -categorical, ordinal or continuous- and the cognitive load increases when the amount of parameters gets too large. In Parallel Coordinates, these problems can be addressed by reducing the amount of axes displayed, or by allowing the user to distinguish between the continuous and categorical axes with a specific layout for each type. Unlike the Decision Tree, the Parallel Coordinates plot gives an overview on the whole dataset -i.e. on each design alternative- at a glance.

Regarding the ability to perform the tasks described in Table 1, the Decision Tree is better suited to show the impact of parameters. It first displays the parameters that best divide the data between the two output classes; an identification of clusters, based on one parameter, is a trivial task. Parallel Coordinates can show the same information, but in a less explicit way: parameters axes can be laid out horizontally according to an impact criterion such as the Information Gain (Safavian and Landgrebe 1990). The C4.5 algorithm (Quinlan 1992) would be suitable to do that.

Parallel Coordinates allow the identification of similarities between dimensions, while the Decision Tree does not. The effectiveness of Parallel Coordinates for this task is highly dependent on the order of axes. Interaction techniques should be implemented to allow the



user to reorder them. The Decision Tree is best to identify families of design alternatives sharing a similar output class.

In the Decision Tree, nodes can be scaled according to the amount of samples included inside them. With two output categories, each node gives two choices and groups parameter values according to this criterion. Thus, a node can represent one or many categories, and does not allow a clear identification of the frequency for each category. Parallel Coordinates show the frequency for each individual category, but the add of jittering and alpha-blending is needed to resolve the over-plotting problems.

A valid solution can be found at any level of the Decision Tree: filtering stops, when the output class of design alternatives under a given node, is homogenous -only valid, or only non-valid design alternatives-. However, this technique is too directive for the user: it forces him to follow a predefined sequence of decisions, returned by the algorithm used to generate the tree, and does not give him a good overview on the solution space. The user has to click on many nodes before being able to assess the validity of a given solution. Moreover, the output range cannot be visualized individually for each design alternative. For example, it is impossible to show only the references that are really close to the output threshold -Pareto front-, or those that are slightly above. The Parallel Coordinates plot offers a broad range of filtering possibilities with the brushing interaction implemented on each axis. However, selecting a range of values makes little sense for categorical parameters, as there is no ranking between them. For categorical parameters, the brushing method should be replaced with a set of checkboxes.

In synthesis, Parallel Coordinates enable a highest flexibility in the dataset exploration and then a better ability to perform tasks useful to support the design process. Decision tree is easier to use, but more limited in terms of data exploration. It is worth to notice that this comparison informs us about the technical possibilities of the different *DVT*, but a usability assessment with their impact evaluation on the design process would be useful to confirm their real added value.

## Conclusions

Human-computer interactions and specifically the information visualization research field already developed data visualization techniques enabling the exploration of large and high-dimensional datasets. However, *BPS* datasets have particular characteristics. They embed multivariate and multidimensional data, which have different levels of correlations and a medium size, generally up to a hundred thousand design alternatives. In addition, the dataset analysis aims to support the design process through specific tasks that might allow to explore, generate or evaluate solutions based on designer's requirements. By crossing *DVT* and *BPS* user requirements, a first selection of techniques has been made in this paper. Parallel Coordinates, Parallel Sets, Scatterplot Matrix, Decision Tree, Dendrogram and Force Directed techniques have been compared, and a qualitative ranking according to our understanding of the literature review allowed the selection of the two most promising of them, namely the Parallel Coordinates and the Decision Tree.

These two *DVT* have been implemented via the smart living building dataset as a case study. Overall, the Parallel Coordinates plot seems best suited since it gives a better overview on the database, and it is more flexible in terms of number of dimensions. However, it requires adding specific visual encodings -jittering, alpha blending- and interaction methods -hiding and moving axes, filtering- in order to be able to perform the tasks described previously. The Decision Tree is less convenient as it cannot represent dimensions without

imposing a ranking to the user, does not give a clear overview on the database, is not appropriate to show the details of individual design alternatives, and does not fit the designer's creative process well.

Parallel Coordinates might be implemented in future *BPS* tools in order to increase the usability of the dataset they generate. Further research would be required to perform a quantitative and qualitative user centred assessment of a broader user population exploring a *BPS* dataset with Parallel Coordinates. Also, the real impact of Parallel Coordinates to direct the design decisions still have to be done.

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## References

- Agrawal, G., Lewis, K.E., and Bloebaum, C.L. (2006) 'Intuitive Visualization of Hyperspace Pareto Frontier'. *Collection of Technical Papers - 44th AIAA Aerospace Sciences Meeting* 12 (January), 8783–8796
- Attia, S., Hamdy, M., O'Brien, W., and Carlucci, S. (2013) 'Assessing Gaps and Needs for Integrating Building Performance Optimization Tools in Net Zero Energy Buildings Design'. *Energy and Buildings* 60
- Bambardekar, S. and Poerschke, U. (2009) 'The Architect As Performer of Energy Simulation in the Performance Based Design'. in *Eleventh International IBPSA Conference* [online] held 2009. 1306–1313. available from <[http://www.ibpsa.org/proceedings/BS2009/BS09\\_1306\\_1313.pdf](http://www.ibpsa.org/proceedings/BS2009/BS09_1306_1313.pdf)>
- Bostock, M. (2017a) *Scatterplot Matrix Brushing* [online] available from <<https://bl.ocks.org/mbostock/4063663>>
- Bostock, M. (2017b) *Collapsible Tree* [online] available from <<https://bl.ocks.org/mbostock/4339083>>
- Bostock, M. (2017c) *Force-Directed Graph* [online] available from <<https://bl.ocks.org/mbostock/4062045>>
- Bostock, M. (2017d) *D3.js - Data-Driven Documents* [online] available from <<https://d3js.org/>>
- Catalina, T., Iordache, V., and Caracaleanu, B. (2013) 'Multiple Regression Model for Fast Prediction of the Heating Energy Demand'. *Energy and Buildings* 57, 302–312
- Chan, W.W. (2006) 'A Survey on Multivariate Data Visualization'. *Science And Technology* (June), 1–29
- Cortellessa, G. (2006) 'Evaluating Mixed-Initiative Systems: An Experimental Approach'. *ICAPS-06* [online] available from <<http://www.aaai.org/Papers/ICAPS/2006/ICAPS06-018.pdf>>
- Davies, J. (2017a) *Parallel Coordinates* [online] available from <<https://bl.ocks.org/jasondavies/1341281>>
- Davies, J. (2017b) *Parallel Sets* [online] available from <<https://www.jasondavies.com/parallel-sets/>>
- Eisenhower, B., O'Neill, Z., Narayanan, S., Fonoberov, V.A., and Mezić, I. (2012) 'A Methodology for Meta-Model Based Optimization in Building Energy Models'. *Energy and Buildings* 47, 292–301
- van den Elzen, S. and van Wijk, J.J. (2011) 'BaobabView: Interactive Construction and Analysis of Decision Trees'. *IEEE S. Vis. Anal.* 151–160
- EU - EPBD (2010) 'Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the Energy Performance of Buildings (Recast)'. *Official Journal of the European Union* 18 (06), 2010
- Harrison, L., Yang, F., Franconeri, S., and Chang, R. (2014) 'Ranking Visualizations of Correlation Using Weber's Law'. *IEEE Transactions on Visualization and Computer Graphics* 20 (12), 1943–1952
- Heeren, N., Mutel, C.L., Steubing, B., Ostermeyer, Y., Wallbaum, H., and Hellweg, S. (2015) 'Environmental Impact of Buildings—What Matters?' *Environmental Science & Technology* 49 (16), 9832–9841
- Heinrich, J. and Weiskopf, D. (2013) 'State of the Art of Parallel Coordinates'. *Eurographics* 95–116
- Hollberg, A. and Ruth, J. (2016) 'LCA in Architectural Design—a Parametric Approach'. *The International Journal of Life Cycle Assessment* 21 (7), 943–960
- Hopfe, C.J. and Hensen, J.L.M. (2011) 'Uncertainty Analysis in Building Performance Simulation for Design Support'. *Energy and Buildings* 43 (10), 2798–2805
- Huot, S. (2005) *Une Nouvelle Approche Pour La Conception Créative: De l'interprétation Du Dessin à Main Levée Au Prototypage d'interactions Non-Standard*. Université de Nantes
- Hygh, J.S., DeCarolis, J.F., Hill, D.B., and Ranji Ranjithan, S. (2012) 'Multivariate Regression as an Energy Assessment Tool in Early Building Design'. *Building and Environment* 57, 165–175

- Ibarra, D.I. and Reinhart, C.F. (2009) 'Daylight Factor Simulations – How Close Do Simulation Beginners "Really" Get?' *11th International IBPSA Conference, Building Simulation 2009* 196–203
- Inselberg, A. and Dimsdale, B. (1990) 'Parallel Coordinates: A Tool for Visualizing Multi-Dimensional Geometry'. *Visualization, 1990. Visualization '90., Proceedings of the First IEEE Conference On* 361–378
- Jochem, E., Andersson, G., Favrat, D., Gutscher, H., Hungerbühler, K., von Roh, P.R., Spreng, D., Wokaun, A., and Zimmermann, M. (2004) *A White Book for R&D of Energy-Efficient Technologies* [online] Switzerland: Novantlantis. available from <<https://goo.gl/UGBiAM>> [2 April 2015]
- Jusselme, T., Cozza, S., Hoxha, E., Brambilla, A., Evequoz, F., Lalanne, D., Rey, E., and Andersen, M. (2016) 'Towards a Pre-Design Method for Low Carbon Architectural Strategies'. in *PLEA2016*. held at Los Angeles, USA
- Kosara, R., Bendix, F., and Hauser, H. (2006) 'Parallel Sets: Interactive Exploration and Visual Analysis of Categorical Data'. in *IEEE Transactions on Visualization and Computer Graphics* [online] held July 2006. IEEE, 558–568. available from <<http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=1634321>>
- Li, J., Martens, J.-B., and van Wijk, J.J. (2008) 'Judging Correlation from Scatterplots and Parallel Coordinate Plots'. *Information Visualization* 9 (1), 13–30
- Lolli, N., Fufa, S.M., and Inman, M. (2017) 'A Parametric Tool for the Assessment of Operational Energy Use, Embodied Energy and Embodied Material Emissions in Building'. *Energy Procedia* 111, 21–30
- Manfren, M., Aste, N., and Moshksar, R. (2013) 'Calibration and Uncertainty Analysis for Computer Models – A Meta-Model Based Approach for Integrated Building Energy Simulation'. *Applied Energy* 103
- Miyamoto, A., Tam Nguyen Van, Damien Trigaux, Karen Allacker, and Frank De Troyer (2015) *Visualisation Tool to Estimate the Effect of Design Parameters on the Heating Energy Demand in the Early Design Phases*. [online] available from <<http://dx.doi.org/10.13140/RG.2.1.1515.2085>> [11 March 2016]
- Moustafa, R.E. (2011) 'Parallel Coordinate and Parallel Coordinate Density Plots'. *Wiley Interdisciplinary Reviews: Computational Statistics* 3 (2), 134–148
- Munzner, T. and Maguire, E. (2015) *Visualization Analysis & Design* [online] available from <<http://public.eblib.com/choice/PublicFullRecord.aspx?p=1664615>>
- Naboni, E., Zhang, Y., Maccarini, A., Hirsch, E., and Lezzi, D. (2013) 'Extending the Use of Parametric Simulation in Practice through a Cloud Based Online Service'. in *IBPSA Italy-Conference of International Building Performance Simulation Association, Bozen, Italy* [online] held 2013. available from <<http://m.e3lab.org/upl/website/publication11111/IBPSAItaly13.pdf>> [11 March 2016]
- Østergård, T., Jensen, R.L., and Maagaard, S.E. (2016) 'Building Simulations Supporting Decision Making in Early Design – A Review'. *Renewable and Sustainable Energy Reviews* 61, 187–201
- Plan Bâtiment Durable (2014) *Rapport# 3 Du Groupe de Travail RBR 2020*. [online] available from <<http://www.planbatimentdurable.fr/publication-du-rapport-3-du-groupe-a846.html>>
- Pu, P. and Lalanne, D. (2002) 'Design Visual Thinking Tools for Mixed Initiative Systems'. *Proceedings of the 7th International Conference on Intelligent User Interfaces - IUI '02* 119
- Quinlan, J.R. (1992) *C4.5: Programs for Machine Learning* [online] 3. vol. 1. available from <<http://portal.acm.org/citation.cfm?id=152181%5Cnhttp://www.amazon.com/C4-5-Programs-Machine-Learning-Kaufmann/dp/1558602380>>
- Reinhart, C.F., Dogan, T., Ibarra, D., and Samuelson, H.W. (2012) 'Learning by Playing – Teaching Energy Simulation as a Game'. *Journal of Building Performance Simulation* 5 (6), 359–368
- Rodriguez, N. and Nancy, R. (2016) *A Survey of Multidimensional Data Visualization Techniques*. (January)
- Safavian, S.R. and Landgrebe, D. (1990) *A Survey of Decision Tree Classifier Methodology*.
- Sartori, I., Napolitano, A., and Voss, K. (2012) 'Net Zero Energy Buildings: A Consistent Definition Framework'. *Energy and Buildings* 48, 220–232
- Schumacher, A. (2017) *Interactive D3 View of Sklearn Decision Tree* [online] available from <<https://bl.ocks.org/ajschumacher/65eda1df2b0dd2cf616f>>
- SIA (2011) *SIA 2040 La Voie Vers l'efficacité Énergétique*. Société suisse des ingénieurs et des architectes
- Tian, W. (2013) 'A Review of Sensitivity Analysis Methods in Building Energy Analysis'. *Renewable and Sustainable Energy Reviews* 20, 411–419
- UNEP (2009a) 'Buildings and Climate Change: Summary for Decision-Makers'. *United Nations Environmental Programme, Sustainable Buildings and Climate Initiative, Paris* 1–62
- UNEP (2009b) 'Common Carbon Metric for Measuring Energy Use & Reporting Greenhouse Gas Emissions from Building Operations'. *United Nations Environment Programme (UNEP)*
- UNFCCC (2015) *Adoption of the Paris Agreement. Report No. FCCC/CP/2015/L.9/Rev.1*. available from <<http://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf>>
- Yandong, L. (2017) *Yandongliu/Learningjs* [online] available from <<https://github.com/yandongliu/learningjs>>

# Translating design details to construction details – with both eyes open

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**Abstract:** Sustainable designs will come to nothing if they are lost in construction process. Therefore, the accuracy of design details and the transformation to the construction details is vital to achieve initial design thinking targets. This is driven most importantly by the fact that the UK Government strategy for all new homes is on the basis of “fabric first” approach to design. This illustrates that priority is on improving energy efficiency through building envelope by increasing insulation thickness; reducing thermal bridging risks as well as making buildings more airtight. This study uses a residential building in Wales, UK as a case study to demonstrate how UK government approach is applied both in design stage and construction stage to meet essential building standards. The methodology includes dynamic thermal simulations, 2D thermal bridge analysis of the construction details and diagnostic test using air permeability test. Results demonstrate that fabric-first approach applied by contractors in housing development is not only able to rectify design errors but also is able to achieve even higher standard levels in some cases.

**Keywords:** Design details, heating and cooling loads, carbon emissions, thermal bridge

## Introduction

In 2007, the UK Government declared their target to move towards the obligation for all new homes to be zero carbon from 2016. As 2016 is now passed, only few zero carbon homes have been delivered. Therefore, UK government announced proposal for all new homes to be nearly zero carbon by 2020 (DCLG, 2007) (Zero Carbon Hub, 2009). These standards aim to improve building envelope through increasing overall insulation thickness, minimizing thermal bridges and making buildings reasonably airtight with air permeability rate set to be no more than  $10.00 \text{ m}^3/\text{h} \cdot \text{m}^2 @ \text{Pa}$  (DCLG, 2007). However, there are widely known barriers that are required to be accurately addressed in order to meet the targets. These barriers generally include (Heffernan, et al., 2015) (Zero Carbon Hub, 2014):

- Well recognized discrepancies between designed and as-built performance
- Some degree of uncertainty is associated with complex building diagnostic tests
- Higher costs in implementation of new technologies and materials to improve building thermal performance

The performance targets of the ‘nearly-zero-carbon’ standard is to be implemented through progressive strengthening of the requirements of Approved Document L1A (ADL1A) ‘Conservation of fuel and power in new dwellings’ (ADL1A) of the UK Building Regulations (DCLG, 2010). This includes improvement to the Accredited Construction Detail specifications for mitigation against thermal losses (Larbi, 2005).

## Methodology-with both eyes open

First step in the holistic study of building performance and meet UK regulations is achievable by using simulation techniques to create an understanding of critical parameters in building design decision-making. The aim is to firstly find out if there is any serious concern to be rectified before construction begins and further use evaluations to improve the quality of construction works and reduce workmanship errors as far as possible. Apparently, neither of these techniques (simulations and in-construction diagnostic tests) are able to deliver low-carbon targets in isolation.

This paper presents a case study for the design of residential units with a practical example to demonstrate the two-level approach [Figure 1 demonstrates the main elements]. This is to implement low carbon objectives for residential homes and to prove that they are useful in determining the suitability of construction details and components, and further highlighting potential problems that can be rectified before the building handover.

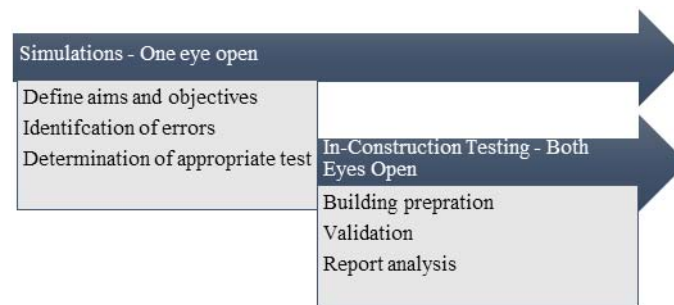


Figure 1. FFA key elements applied to the case study

### Case study

The following case-study documents the construction detail assessment and the fabric performance testing in dwellings in a multi-storey apartment building, located in Cardiff, Wales, UK. The project is a 55-unit residential homes with lightweight steel frame structure (Figure 1 shows the plans of the project). In order to evaluate energy consumption and carbon emissions, heating and cooling loads are calculated where heating set point is adjusted at 22°C and cooling setpoint is adjusted at 28°C. Project has met the compliance of Scottish standard. Table 1 shows fabric details and heating systems of the project as specified in SAP worksheet. Total floor area for ground floor to 3rd floor is 804m<sup>2</sup> and 270m<sup>2</sup> for 4th and 5th floor (overall building floor area is 3756m<sup>2</sup>).

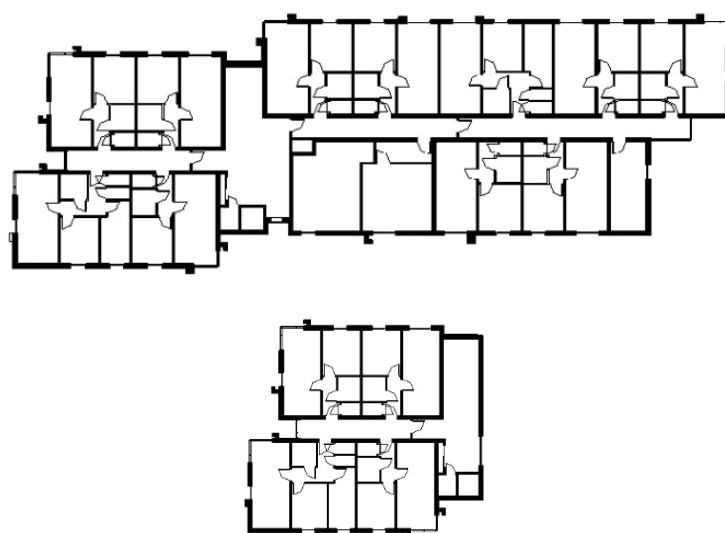


Figure 2. top) ground floor to 3<sup>rd</sup> floor, bottom) 4<sup>th</sup> and 5<sup>th</sup> floor



Table 1. Fabric details and heating systems

Fabric	Type	Detail
External Wall 1	Hybrid Steel frame construction	U-Value 0.17
Sheltered Wall 1- to unheated communal areas	Twin steel stud construction	U-Value 0.18
Party wall 1	Fully filled and sealed party wall	
Floor 1- Ground	Solid concrete 150mm slab	U-Value 0.17
Floor 2- Over Plant room	No flats over this area	U-Value 0.18
Roof	Warm flat roof construction	U-Value 0.11
Windows	Based upon aluminium windows	U-Value 1.5
Doors – to unheated communal areas		U-Value 1.5
<b>Heating Systems</b>		
Main heating	Community heating based on gas boilers	88.6% efficiency
Heat distribution	Pre-insulated low temperature/ variable flow	
<b>Other</b>		
Lighting	100% low energy lighting	
Ventilation/ Mechanical Cooling	Mechanical ventilation is used/ no mechanical cooling	

Initial simulations work provided an opportunity to identify potential weaknesses in building. Dynamic thermal simulations is also capable of showing carbon emissions during the year. The importance of carbon emissions analysis is due to the fact that UK building regulations set out the Target Emission Rate (TER) as a minimum allowable standard (expressed in annual kg of CO<sub>2</sub> per m<sup>2</sup>) for the building performance. The CO<sub>2</sub> emission rate of a building is measured on the basis of its actual specifications and is expressed as Dwelling Emission Rate (DER) for residential buildings (excluding common areas). This is the annual CO<sub>2</sub> emissions of the proposed dwelling expressed in kg/m<sup>2</sup>. Typical TER for new dwelling, on gas, is usually around 20- 25kg CO<sub>2</sub>/m<sup>2</sup> per year (HM government, 2010).

### Energy and carbon emissions

Cardiff has a mild humid temperate climate with warm summers and no dry season [See Figure 3 for monthly average dry bulb temperature]. During the year, typical wind speeds differ from 1 m/s to 9 m/s and rarely exceeds 14 m/s. Figure 4 demonstrates heating loads required to keep operative temperature above 22 °C for the entire building. Building consists 55 units and 12 units are located in the south side of the building and therefore are expected to consume less energy loads compared to other units. The wind is most often towards the west and less toward east and north east. Such strong winds are expected to have an impact on overall heating loads for units on theses sides.

Dynamic thermal simulation software used in this study was DesignBuilder which Employs EnergyPlus as its calculation engine. The software is highly validated within building performance researchers and professional construction developers (Bahrevand, et al. 2013) (University of Northumbria, n.d). For simplification of thermal modelling, comfort zone is considered to be between 22°C and 28°C. This domain is highly likely to be within comfort zone, although a number of factors could have an impact on thermal comfort which includes humidity, activity and clothing level of the occupants, physiological and psychological factors, etc. (Sajjadian, et al., 2013).

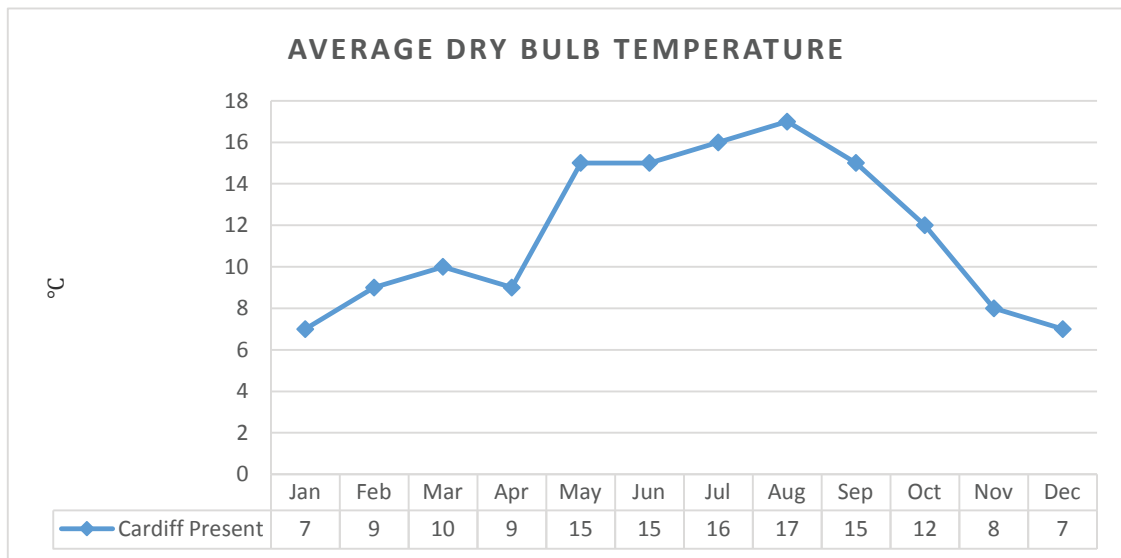


Figure 3. Average monthly dry bulb temperature, Cardiff

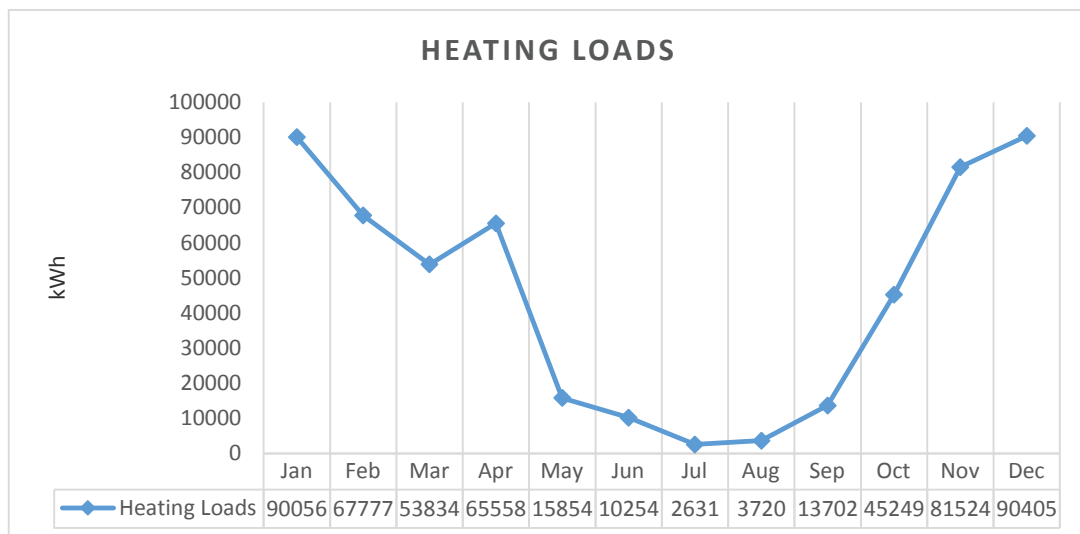


Figure 4. Heating loads per month for the entire building

As Figure 4 shows, major heating loads are consumed in January and December months and minimum is in July. Building benefits from mechanical ventilation and meets UK regulations for infiltration rate. These design strategies were successful to remove overheating risk and no cooling loads are required in summer months. Figure 5 shows carbon emissions per month for the entire building. Carbon emissions also include the usage of lighting inside the building (specification is given in table 1). As the overall building carbon emissions exceeds TER, therefore the building used 13.6 kWp of solar panels in order to reduce CO<sub>2</sub> emissions to meet building regulations.

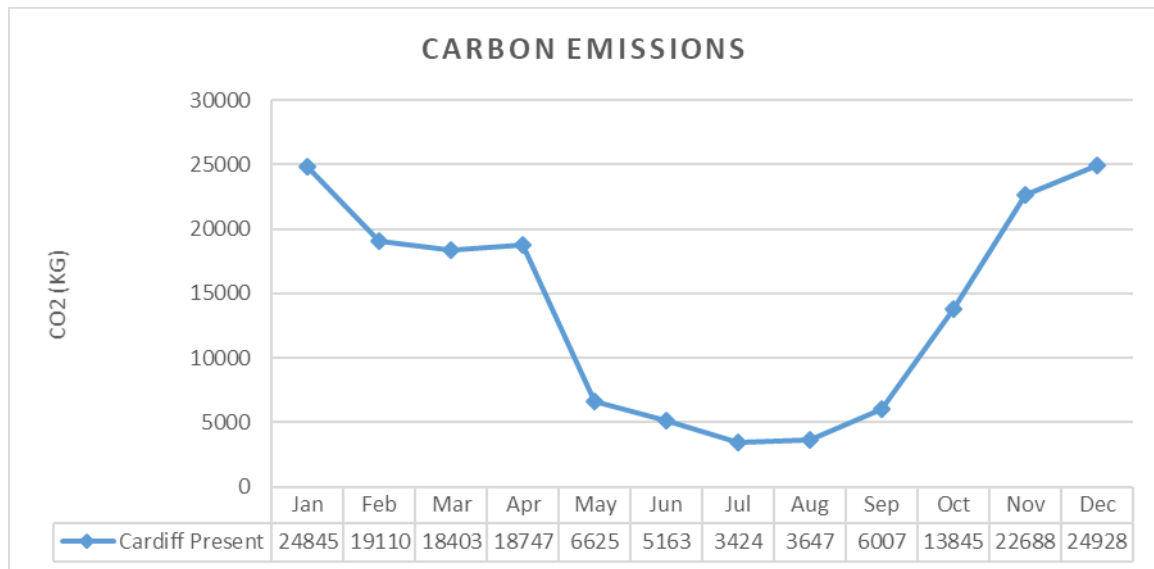


Figure 5. Carbon emissions per month for the entire building

As Figure 5 shows most carbon emissions are consumed in January and December months as it was expected from heating loads requirements. The impact of lighting came as a surprise with considerable effect even though building benefits from 100% low energy lighting. Simulation works did not include electrical equipment for Kitchen and other areas. Therefore, actual building carbon emissions are expected to be higher during operation. Another important factor that could have an impact on energy loads and consequently on carbon emissions is the uncertainty with regards to thermal comfort of occupants. Even though the 22 to 28°C set for simulations is highly likely to be within comfort zone, however, there is a possibility of considerable change during building operation.

### Thermal bridge analysis

Thermal bridging in buildings can cause multitude of problems, including added energy use and interior surface condensation problems (Larbi, 2005). Thermal bridges are discontinuities in any thermal barrier and are more noticeable when the material creating the bridge is highly conductive. In order to deliver project with minimum errors, several junctions of the projects were investigated by THERM software (2D) for the possibility of thermal bridge risk. Results aim to minimize energy loss and limit the risk for condensation by improving design details and rectifying potential errors. Typical interface conditions modelled include curtain wall, roof-to-wall and wall-to-fenestration.

#### **Roof-to-wall interface**

Architects considered the insulation strategy for the wall and the roof; however, the interface between the two seems to need more attention for thermal continuity. Figure 6 shows thermal bridge analysis in 2D. For a parapet detail, the insulation for the wall is not brought above the underside of the roof deck. This result in a parapet wall becomes a heat fin and the heat loss is dependent on the thickness of the roof deck as well as the climate. A suggestion is made during the construction process to bring up insulation over the parapet and tie it into the roof insulation system. Further 3D details are also required by architects to show coordination with the installation of the air barrier and water management systems to ensure that these systems are not damaged by the insulation strategy.

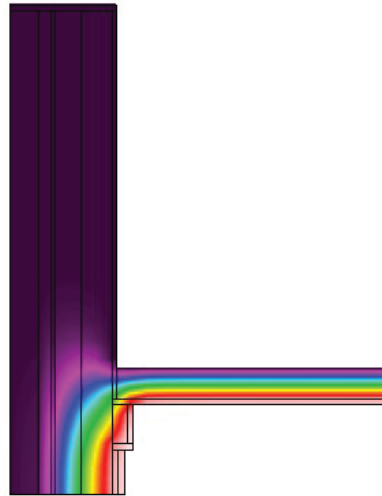


Figure 6. 2D thermal bridge analysis with THERM

### ***Curtain walls***

Curtain walls are more common in commercial buildings than residential ones because of the utilization of large glazing area in curtain walls and the moderately low thermal performance of glass and metal. Therefore, compared to the opaque insulated façades, energy consumption in buildings with curtain walls is more sensitive to climatic conditions. However, the advancement in technology improves their thermal performance. Fabricators considered thermal breaks for all the curtain walls used for this case study and due to insufficient information from supplier on what materials are used as thermal breaks, thermal conductivity is assumed to be minimum and set as 0.1 W/M°C for simulations. As shown in Figure 7 no thermal bridge is identified for the curtain walls.

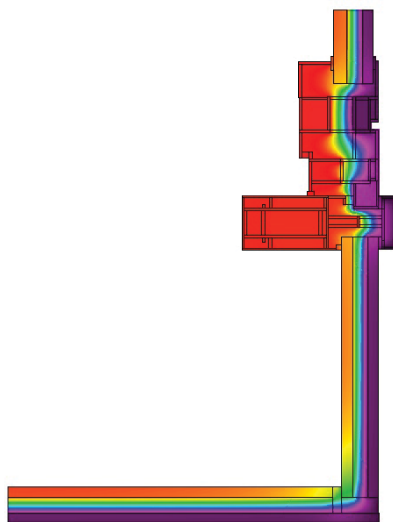


Figure 7. Curtain wall 2D thermal bridge analysis

### ***Wall-to-Fenestrations***

One of the most frequent locations for thermal bridge risk is located at fenestration interfaces. Window-to-wall and door-to-wall interfaces create further challenges for energy considerations and condensation risk because of the positioning within the rest of the assembly. Figure 8 shows thermal breaks used for doors and louvers of the project in ground floor were unable to entirely remove thermal bridge risk. However, this was an

ignorable junction for the project because the location was not directly connected to residential space.

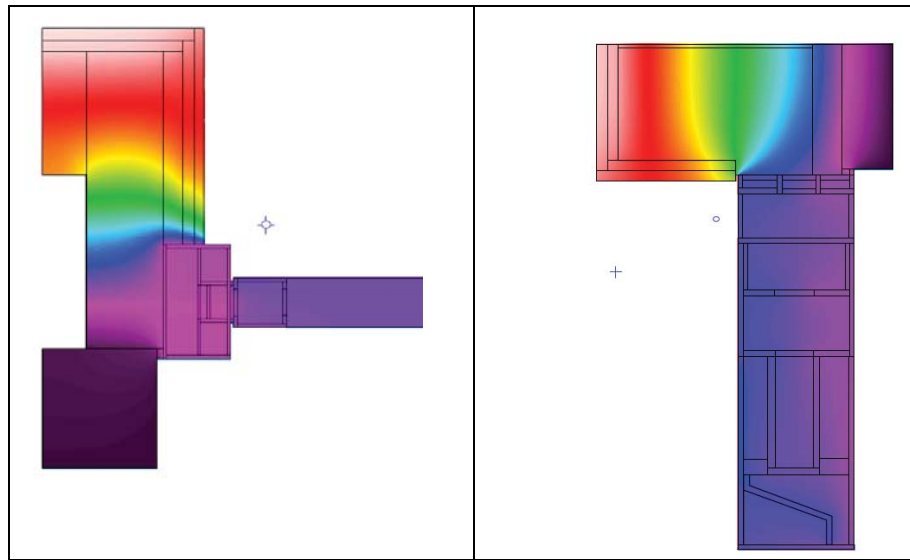


Figure 8. Wall-to-door and louver thermal bridge analysis

### In-construction diagnostic test, Air Test

Considerable gap exists between as-built and predicted energy performance by computer simulations in the UK context. The combination of thermal modelling and diagnostic tests are able to enhance the possibility to identify potential failures either during construction process or in the early design stage. An important factor that is considered in the assessments in this study is air tightness of building that impact air movement in and through the building envelope. Heat and moisture flow in building are affected by this air movement through openings or cracks in the building envelope. In order to measure airtightness, air permeability is used which is defined as air leakage rate per hour per square meter of envelope area at 50 Pascal. The calculation of Building's energy could only be reliable after confirming that the build has met the suggested rate during the diagnostic test. Otherwise, the energy consumption in buildings cannot meet the calculated values at the initial design stage.

Air permeability of  $4.00 \text{ m}^3/\text{hm}^2$  was set as a target by the contractor for the each dwellings in this case study. Dry run air test was carried out for one of the flats at the north side of the building in compliance with the procedures by "The British Institute of Non-Destructive Testing" (BINDT) using an air depressurisation technique (ATTMA TS1) (ATTMA, 2010) incorporating the whole building envelope at an imposed pressure of 50 Pa. Air was supplied by the fan to the flat at a variety of flow rates to create a pressure differential between inside and outside of the flat. The results of the pre-handover test carried out shows the rate of  $2.94 \text{ m}^3/\text{hm}^2$  which was better than the target design limit and well below the maximum allowable level of  $10.00 \text{ m}^3/\text{hm}^2$  at 50 Pa as required by Part L1A 2010. During the test, it was possible for the author to locate some air leakage points without performing smoke test and it appeared to be mostly around the waste pipe connecting to the SVP boxing in the bathroom area, the aerial sockets on both partitions and exterior wall as well as some electrical sockets in the kitchen. Therefore, despite the successful results, it was noticed that further improvement is still possible to achieve should the leakage areas are addressed accordingly.



## Conclusions

In order to comprehensively assess energy consumption in buildings, it is essential to consider all sources of uncertainty that may have an impact on the predictions, since the early stages of design decision-making. Therefore, this paper demonstrates the current approach generally used by contractors in order to respond to these challenges. It is concluded that the method used by contractors that included both simulations and in-construction diagnostic test is not only able to meet current UK government regulations but also has the potential to meet stricter targets in future. Therefore, it is a future proof method which can deliver even higher quality buildings to occupants. The method suggests several principles that can be applied for other constructions in order to control energy consumption and significantly reduce thermal bridging. These principles are:

- Roof-to-wall interfaces make additional challenges that require to be carefully reviewed for energy managements as well as condensation risk.
- Careful design, combined on site testing and pre-construction computer modeling evaluation are essential tools to meet UK government targets for 2020
- Even though the case study achieves noticeable improvement in infiltration rate with FFA approach, further strategies are required to eliminate the need for PV panels and meet TER by reducing the U-Value for external walls.

Further studies might include thermography and co-heating tests in order to provide further understanding in translation of design details to construction details.

## References

- ATTMA. (2010). *ATTMA*. Retrieved from Technical Standard L1-The Air Tightness Testing & Measurement Association. 2010. Measuring air permeability of building envelopes (dwellings). Sheffield, UK: <http://www.attma.org/downloads/ATTMA%20TSL1%20Issue%201.pdf>.
- Bahrevand, M., Bin Ahmed, M., Safikhani, T., & Abdul Majid, R. (2013). DesignBuilder Verification and Validation for Indoor Natural Ventilation. *Basic and Applied Scientific Research*, 182-189.
- DCLG. (2007). *Building a Greener Future: policy statement*. London: Department for Communities and Local Government.
- DCLG. (2010). *Building Regulations 2000: Approved Document L1A Conservation of fuel and power in new dwellings October 2010 edition*. Department for Communities and Local Government.
- Heffernan, E., Pan, W., Liang, X., & De Wilde, P. (2015). Zero carbon homes: Perceptions from the UK construction industry. *Energy Policy*, 23-36.
- HM government. (2010). *Approved Document Part L1A: Conservation of fuel and power in new dwellings (2010 Edition)*. London: Communities and Local Government.
- Larbi, A. (2005). Statistical modelling of heat transfer for thermal bridges of buildings. *Energy and Buildings*, 945-951.
- Sajjadian, S., Lewis, J., & Sharples, S. (2013). Interpretation and determination of thermal comfort in climate change context. *International Post Graduate Research Conference IPGRC 2013* (pp. 1106-1113). Salford: University of Salford.
- University of Northumbria. (n.d.). *An inter-program Analysis of Computational Fluid Dynamic Based on PHOENICS and DesignBuilder software*. Newcastle.
- Zero Carbon Hub. (2009). *Defining a Fabric Energy Efficiency Standard for Zero Carbon Homes: Task Group Recommendations*. London.
- Zero Carbon Hub. (2014). *Carbon compliance for tomorrow's new homes: a review of the modelling tool and assumption topic 3: Future climate change*. London: Zero Carbon Hub.

# Predicting Daylight Autonomy Metrics Using Machine Learning

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**Abstract:** This study analyses the efficacy of using machine learning through artificial neural networks (ANN) to predict daylight autonomy metrics in typical office spaces. Based on a literature review of the use of ANN for non-linear problems, the chosen approach was deemed promising for its use in predicting daylight performance with the assumption that previous training data can be provided. The ANN approach, while empirical, has advantages when compared to conducting full simulations in the areas of speed and computing resources. In this study, several network architectures were analysed against several test cases. The accuracy of the obtained results mirror those in other studies when applied to daylight autonomy metrics. In addition, accuracy improved with the addition of a larger set of training data as well as the enhancement of the network architecture itself.

**Keywords:** Daylight, Daylight Autonomy, Machine Learning, Neural Networks

## Introduction

In the field of sustainable building design, daylighting is an emerging design factor improving the performance of a building (Bodart and De Herde, 2002; Pollock *et al.*, 2009). Good daylight design has been shown to have a positive impact on human health and performance (Heschong, Wright and Okura, 2002) and the potential to create visually pleasing indoor environments (Galasiu and Veitch, 2006). To date, however, predicting daylight performance required computationally expensive simulations that may not be feasible in a highly iterative design process (Hu *et al.*, 2014). This paper introduces an alternative approach to predicting daylighting performance using machine learning and artificial neural networks (ANN) that have been previously shown to be suitable for complex non-linear problems (Suykens *et al.*, 2012).

The assessment of daylight using climate-based metrics is increasingly gaining recognition as a design tool improving occupant comfort and reducing energy consumption. This paper focuses on daylight autonomy (DA300lux) as a suitable metric for daylight performance due to its increasing adoption (Reinhart and Fitz, 2006). The definition of Daylight Autonomy (DA) was first given by the Association Suisse des Electriciens in 1989 (Reinhart *et al.*, 2013) and further developed as a measure for the percentage of occupied hours in which a minimum illuminance threshold at a sensor point can be maintained by daylight alone (Reinhart and Walkenhorst, 2001). The target used depends on the determined use of the space – typically 300 lux or 500 lux for office work.

Briefly, artificial neural networks (ANN) are computer models made of units called neurons, arranged in an input layer (that accepts input parameters), an output layer (which provides the actual prediction) and a varying number of hidden layers in the middle (Figure 1). Using varying strengths, the connections between neurons transmit an activation signal from one neuron to another (Jain *et al.*, 1996). Backpropagation is a typical method to train neural networks. The backpropagation algorithm uses gradient descent to adjust the connection weights and to find the minimum value of the error function (Rojas, 1996).

The next section of the paper briefly reports on previous research in the areas of predicting building thermal and daylighting performance using backpropagation neural

networks. Following that, the methodology used in this study is described, including the design setup of the model and the various network architectures and settings. Consecutively, the obtained results are reported. The last section of this paper reflects on the overall approach and findings and outlines recommendations for future work.

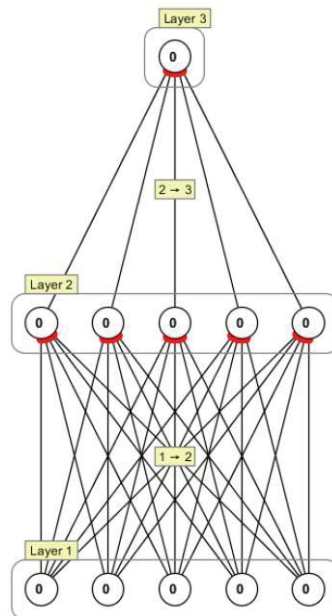


Figure 1. Neural network architecture (Simbrain, 2017) with five neurons in the input and hidden layer (Layer 1, Layer 2) and one neuron in the output layer (Layer 3)

### Predicting building performance using neural networks

Several researchers have studied the application of neural networks for predicting building energy performance including heating and cooling loads and the overall energy consumption of buildings with successful results (Wong *et al.*, 2010; Zhao and Magoulès, 2012). Studies show that the accuracy of these predictions does not fall behind that of other thermal simulation tools (Neto and Fiorelli, 2008), making neural networks a possible alternative approach to time-consuming and computationally expensive simulations. This can be feasible only if the required data is within a set design scope and previous measurements are available for training the neural network. The successful application of neural networks in thermal building performance and their ability to address non-linear problems suggest that they may be applicable for daylight analysis. Thus, this paper sets out to experiment with using back-propagation neural networks to predict daylight performance and the Daylight Autonomy metric.

Compared to the implementation of neural networks for thermal predictions, research is rather sparse on the implementation of neural networks for daylighting and illuminance predictions. However, the few results that are available are promising: In a study by (Lopez and Gueymard, 2007), a neural network was used to predict the luminous efficacy under cloudless conditions, suggesting a possibility to predict the illuminances on surfaces based on measurements of solar irradiance. In another study, Janjai and Plaon were able to predict sky luminance for a year, giving more accurate results than the CIE model for clear and overcast skies, but not for cloudy skies (Janjai and Plaon, 2011). Comparisons have also been made between different models for predicting sky irradiance and illuminance and neural networks showed superior performance (Pattanasethanon *et al.*, 2008).

Neural network-based modeling has also been successfully applied to predicting the horizontal illuminance in an office building (Kazanas *et al.*, 2009). The results had a low average error of 3% when compared to measured illuminances. In a classification problem, a similar study was able to determine the category of climate-based metric UDI (classification problem) for various ranges of lux levels (<100 lux, 100 – 2000 lux, >2000 lux) with a high accuracy of 96% when combining a neural network with principal component analysis (Zhou and Liu 2015). These studies suggest neural networks can be used as a computational tool with potentially very accurate prediction capabilities given appropriate model selection and well-defined parameters.

Achieving accurate results was a key point in the above studies. Nonetheless, it should be noted that some of the studies also faced challenges and occasional failures. This seems to be the case especially when the input parameters are complex and have a wider range of values (e.g. Janjai and Plaon, 2011; Conraud-bianchi, 2008) and is consistent with findings in the application of neural networks for thermal comfort predictions (Magnier and Haghighat, 2010) and those aiming to include occupant behavioural patterns (Neto and Fiorelli, 2008). Therefore, it becomes evident that there is a necessity to accurately retrace input parameters that impact any variations in the results, and empirically search for a neural network architecture that is capable of reconstructing more complex and dynamic relationships.

There is not yet sufficient research that explores the range of application possibilities for ANNs to measure daylight performance within buildings. The lack of studies undertaken in this field also points to a need for validation and a more thorough investigation of the advantages and limitations of this approach. Regarding daylighting predictions, the need for training data to include various climate and sky conditions as well as sun positions has made generating the training data for neural networks a tedious task, albeit one that can be used to generate instantaneous results thereafter.

This study uses a backpropagation neural network to measure Daylight Autonomy over the course of a year, thereby bypassing the need to use sky conditions and sun positions as input parameters as well as conducting intensive simulations or recording measurements associated with collecting the data.

## **Methodology**

### ***Design setup***

A generic typology for the ground floor of an office building was developed to investigate the performance of neural networks for the prediction of daylight autonomy (Figure 2). As part of the process of generating the target data required for training the neural network, the daylight autonomy calculations were done using Diva for Rhino. Diva is a radiance-based and validated tool (McNeil and Lee, 2012) that uses the daylight coefficient approach to determine the daylight contributions for all sensor points within a building (Bourgeois *et al.*, 2008). The daylight autonomy was determined for a horizontal illuminance of 300 lux for 300 sensor points that were generated at a work plane height of 85 cm. The internal reflectance values within the building were set to 20%, 50% and 70% for floor, walls and ceiling, respectively. The daylight autonomy results for all sensor points were then extracted for further application in the neural network.



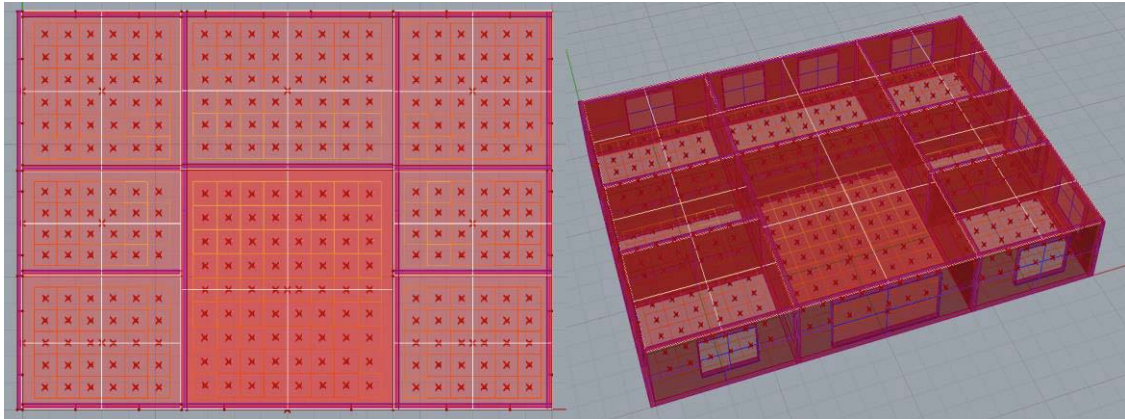


Figure 2. Layout A: Illustration of basic building model geometry and the location of sensor points

The design variables affecting the daylight autonomy results were identified as follows:

- The X-Y coordinates of the sensor locations to identify the different points
- A unique room ID was assigned to specify the rooms in which the sensor points were located as seen in (Kazanasmaz *et al.*, 2009)
- The average distance of the sensor points to the center of the windows to describe proximity of the sensor points to the light source.
- The overall dimensions, window dimensions, number of windows and their respective orientation. Window orientation was represented using four input parameters, one each describing the north, south, east and west orientations as a binary value.

The input parameters were treated as continuous variables and normalized between the range 0 and 1 with 0 indicating the minimum value of the variable and 1 its maximum.

#### ***Automated data generation using Grasshopper***

The building design was parametrically built in Grasshopper for Rhino (Figure 3). The above identified input parameters were extracted within Grasshopper and assigned to each of the sensor points in the building. The data was then exported as an excel sheet to convert it into the training data for the neural network.

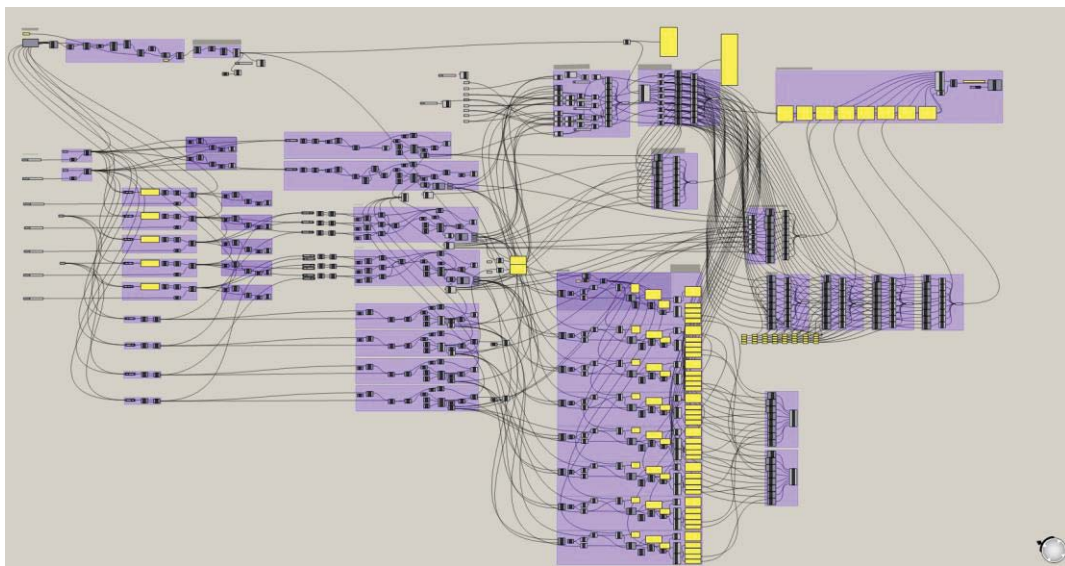


Figure 3. Layout A: Illustration of basic building model geometry and the location of sensor points



## Neural network training and testing

A feed---forward neural network was chosen as a baseline for training and this application. The neural network was trained using the backpropagation method (Hecht---Nielsen, 1989) using the software tool Simbrain (Simbrain, 2017). A sigmoidal activation function was chosen in the hidden as well as output layers and all weights were randomized before training. The training and testing of the neural network was carried out in four parts as outlined below.

1) Neural network training with one and two hidden layers: In an experiment, several neural network architectures were trained by changing the number of hidden layers and the number of neurons they contain. Although a rule of thumb suggests that the number of neurons from input to output layer should follow a pyramidal rule --- for example 7 neurons in the first layer, 5 neurons in the second layer and 1 neuron in the third layer (Joe, 2009), other studies have more successfully implemented a higher number of neurons in the hidden layer than the number of neurons in the input layer (Chow *et al.*, 2002; Conraud---bianchi, 2008; Zhou and Haghighat, 2009).

For the above outlined building, 300 sets of data were generated for each sensor point. 10% of the data was withheld for validation of the neural network. The network was then trained with a momentum of 0.7 and a learning rate of 0.25. No maximum number of epochs was selected, although training was halted when either the mean square error (MSE) did not go down any further or when the results deteriorated with further training. In this way, the MSE was calculated for several neural networks with a varying number of neurons in architectures with both one and two hidden layers. The set up of the network architecture and the corresponding results are listed in Table 2.

2) Neural network training and validation using different input parameters: Having established the MSE results for different neural network architectures, the prediction power for the DA300lux metrics was tested using four different sets of input parameters (Table 1). The first set maintained all parameters as described above while the second set removed the coordinates as identifiers of the sensor points. In the third set, the coordinates were added back as input parameters, but the distances of sensor points to windows were removed. The fourth set omitted the room ID as an input parameter. This input parameter was considered a duplicate, as the attributes of the rooms were already described through the remaining input parameters.

Table 1. Input data used for neural network training

Input Parameter Set A	Input Parameter Set B	Input Parameter Set C	Input Parameter Set D
Room dimension	Room dimension	Room dimension	Room dimension
Window dimension	Window dimension	Window dimension	Window dimension
North orientation	North orientation	North orientation	North orientation
South orientation	South orientation	South orientation	South orientation
East orientation	East orientation	East orientation	East orientation
West orientation	West orientation	West orientation	West orientation
No. of windows	No. of windows	No. of windows	No. of windows
Average distance to windows	r	Average distance to windows	Average distance to windows
-	Coordinates of sensor points	Coordinates of sensor points	Coordinates of sensor points
Room ID	Room ID	Room ID	-

3) Daylight Autonomy predictions for an alternative layout: The validation of the neural network in the above outlined part was done for sensor points set within the design scope from which the training data was taken. To stress test neural network predictions, an alternative layout (Layout B) was developed, for which the DA values were then calculated. Alongside the location of sensor points, the room dimensions as well as the location of windows were changed. The alternative layout is illustrated in Figure 4. The test used input parameter set C as it had previously yielded the best results. Additionally, an ANN constituting of 15 neurons in the hidden layer was used for training as preliminary results gave a low MSE of 0.006 for said architecture when trained with 300 data points. Although it was expected that there would be a larger error margin based on the numerous design changes affecting daylight performance, this case was chosen as an initial assessment to gauge the performance of neural network predictions in a changing design scope.

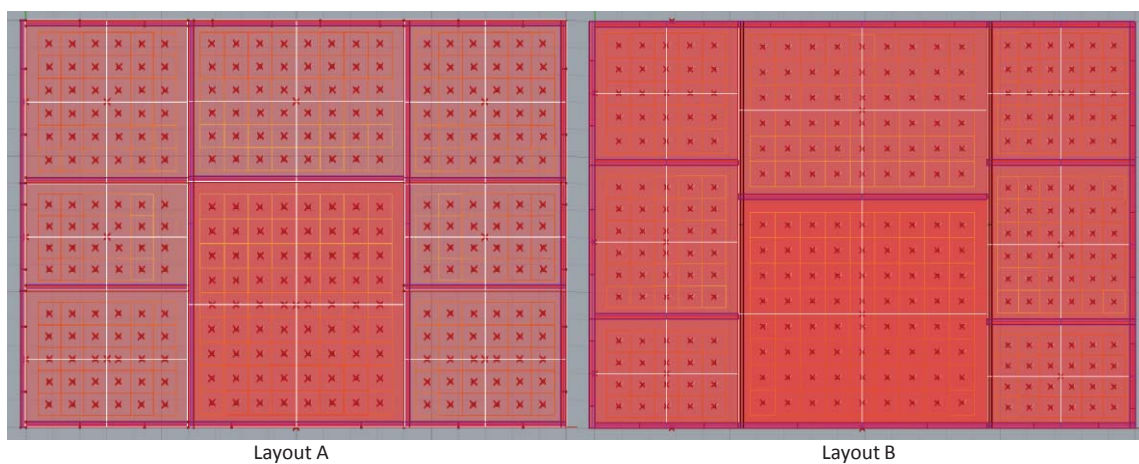


Figure 4. Basic building layout used for training (Layout A --- left) and an alternative layout developed for validation (Layout B --- right)

4) Daylight Autonomy predictions for a single room with varying depth: In a fourth test, the above experiment was simplified. Under the assumption that neural networks function as a model mimicking the behaviour of a building, with an innate potential to adjust to a changing design scope based on the training data provided to the neural network, DA predictions were made for a singular south facing room, where the design was varied only by changing room depth and sensor point location (Figure 5). Predictions were made with an increasing number of training data sets and results were compared using neural networks with one and two hidden layers.

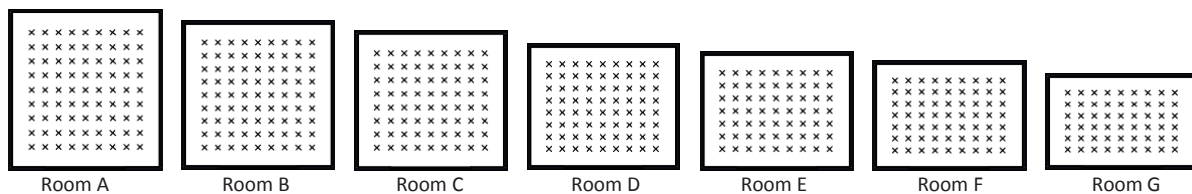


Figure 5. Rooms used for progressive network training

## Results

### *Neural network training results for networks with one and two hidden layers*

Several neural network architectures were tested to determine the impact of the number of neurons and number of hidden layers on the ability of the neural network to fit the input data to the provided target data (prediction results). The achieved MSE results for each of the tested ANN architectures are shown in Table 2.

The ANNs with one hidden layer yielded a lower MSE than ones with two hidden layers. The three-layered ANNs also seemed to reach convergence at an MSE of 0.0011 when implementing both a higher and lower number of neurons in the hidden layer than number of neurons in the input layer, confirming the above outlined assumption that the ANN architecture does not need to be formed of a pyramidal structure.

Table 2. MSE results for varying neural network architectures

No. of hidden layers	No. of neurons within hidden layers	MSE
1	5	0.0017
1	9	0.0011
1	12	0.0011
1	15	0.0011
2	5-5	0.0022
2	7-5	0.0019
2	9-5	0.0028

### *Neural network training and validation using different input parameters*

Following the initial testing of neural network architectures, the architecture with twelve neurons in one hidden layer was selected to predict the DA results using the four different sets of input parameters outlined in Table 1 above. The MSE for the data sets is shown in Table 3. The results reveal that both coordinates of sensor points and average distance of sensor points to the windows lower the MSE. The neural network results could further be improved by removing room ID as an input parameter, achieving an overall improvement of the MSE from 0.0013 to 0.0007. This impact of the MSE results becomes clearer in the error analysis of the input sets (Figure 6). A lower MSE led to better DA predictions and an average prediction error ranging between 3.5% to 2.3% for the different input parameters, thereby providing results comparable to those from validation studies done for daylight analysis using Daysim and Radiance (Reinhart and Walkenhorst, 2001).

Table 3. MSE results for varying input parameter sets

	MSE
Set A	0.0011
Set B	0.0013
Set C	0.0007
Set D	0.0008

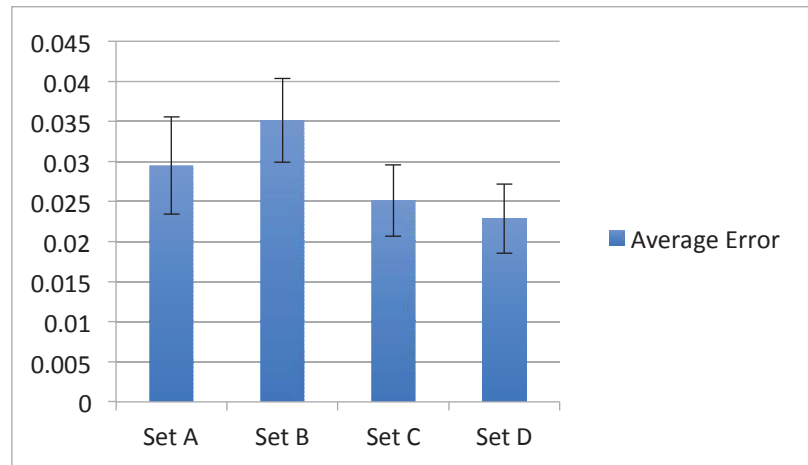


Figure 6. Prediction errors obtained for the varying input parameter sets

Additionally, the errors obtained for each of the sensor points are presented in Figure 7. The error rates of the predictions are of a volatile nature and show no apparent consistency between implemented input parameter set and error, meaning errors can be lower for a specific sensor point using one input set, but higher for another sensor point. Further analysis of the data shows that the errors using input parameter sets C and D are less erratic, suggesting a more robust neural network.

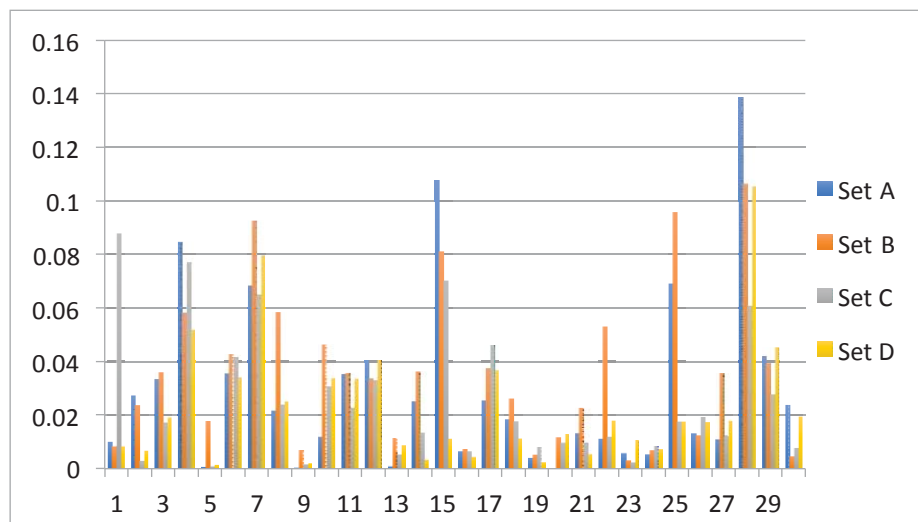


Figure 7. Prediction errors obtained for each sensor point

### ***Daylight Autonomy predictions for an alternative layout***

The overall error for the DA predictions for building layout (B) with new room dimensions, window positions and sensor point locations increased from 2.3% to 7.66%. The error for each of the sensor points is shown in Figure 8. A noticeably lower error was achieved for rooms with smaller changes in dimensions and the corner rooms with windows facing two orientations. A further analysis of the results revealed that the error gradually increased towards the rear for each room with one orientation.

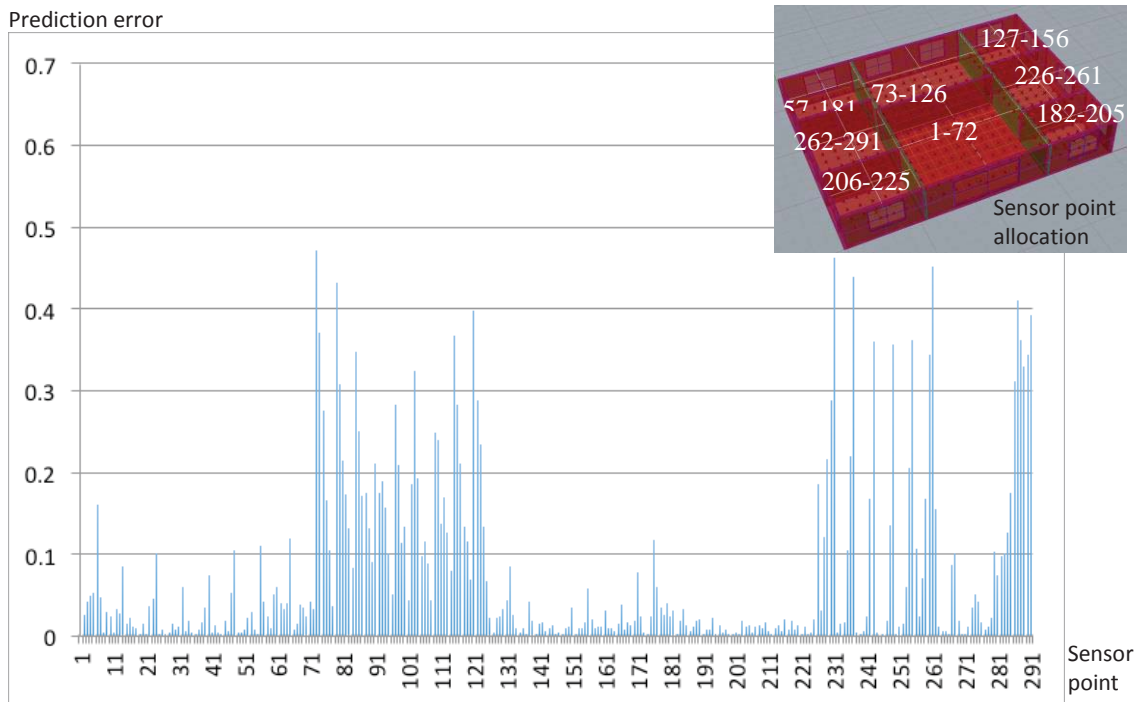


Figure 8. Prediction errors obtained for each sensor point on an alternative layout

### ***Daylight Autonomy predictions for a single room with varying depth***

Neural network training and testing results for DA predictions for rooms C, G and D are given in Tables 4, 5 and 6, respectively. As shown in these tables, as the number of training data increased (by adding more rooms) the error margins decreased. Additionally, neural network architectures with one as opposed to two hidden layers generally better fit the training data, as indicated by lower mean square errors (MSE). Nonetheless, when considering average error rates, neural network architectures with two hidden layers on average showed much better results than networks with one hidden layer. Analyses did however reveal one peculiar result: neural network training for DA predictions for room G (Table 5) led to an unexpectedly strong increase in average error when including room D into the analysis. This increase in error rate from 4.46% to 28.96% for one hidden layer and an increase from 1.96% to 2.07% for two hidden layers might hint towards over-fitting.

Table 4. Neural network training and testing results for DA<sub>300lux</sub> predictions of Room C

Training Data	MSE		Average Error	
	One hidden Layer	Two hidden Layers	One hidden Layer	Two hidden Layers
Room A	0.0006	0.0011	41.54%	41.54%
Room A+E	0.0007	0.0014	25.18%	6.93%
Room A+E+G	0.0005*	0.0013	15.64%	6.93%
Room A+B+E+G	0.0009	0.0013	4.68%	3.10%
Room A+B+E+F+G	0.0007	0.0012	3.21%	3.32%
Room A+B+D+E+F+G	0.0008	0.0012	3.25%	3.30%

\*A neural network architecture of 4-25-1 neurons was chosen for this training data set as it had provided a lower MSE in preliminary testing. All other results were compiled using a network architecture of 4-20-1 and 4-



20-4-1 neurons in the layers.

Table 5. Neural network training and testing results for DA<sub>300lux</sub> predictions of Room G

Training Data	MSE		Average Error	
	One hidden Layer	Two hidden Layers	One hidden Layer	Two hidden Layers
Room A	0.0006	0.0011	78.76%	79.17%
Room A+E	0.0007	0.0014	21.11%	3.11%
Room A+C+E	0.0008	0.0012	14.52%	2.92%
Room A+B+C+E	0.0008	0.0012	13.16%	2.78%
Room A+B+C+E+F	0.0007	0.0012	4.46%	1.96%
Room A+B+C+D+E+F	0.0007	0.0012	28.96%	2.07%

Table 6. Neural network training and testing results for DA<sub>300lux</sub> predictions of Room G

Training Data	MSE		Average Error	
	One hidden Layer	Two hidden Layers	One hidden Layer	Two hidden Layers
Room A+B+E+F+G	0.0006	0.0012	1.81%	2.53%

## Conclusion

One of the limitations of using ANNs is their empirical nature. Researchers often develop an intuition about the suitability of various network architectures and settings that best fit a given problem. Yet, once these issues are overcome, ANNs provides an excellent alternative to solving complex and non-linear problems. Promising initial results in this study point to the efficacy of using artificial neural networks for predicting daylighting performance in simple office spaces. As predicted, an increase in training data generally yielded better accuracy in the predicted results. Additionally, the use of two hidden layers improved the results in most cases. Overall, the error margins were within an acceptable range using less time and computational resources than computer simulations. The suitability of this approach, however, is dependent on a cost-benefit analysis regarding the ratio between the needed input training data and the required number of predictions since generating the training data continues to depend on conducting full computer simulations or real-world measurements. An intriguing possibility, that is yet to be explored, is the use of predicted data as training input for subsequent predictions. This heavily depends on the robustness of the process and the accuracy of the predictions. Data drift and thus accuracy deterioration could prove a limiting factor. Additional planned future work includes experimentation with more complex design scenarios, fine tuning the validation process and increasing the robustness of the overall research methodology.

## References

- Bodart, M. and De Herde, A. (2002) 'Global energy savings in offices buildings by the use of daylighting', *Energy and Buildings*, 34(5), pp. 421–429. doi: 10.1016/S0378-7788(01)00117-7.
- Bourgeois, D., Reinhart, C. F. and Ward, G. (2008) 'Standard daylight coefficient model for dynamic daylighting simulations', *Building Research & Information*, 36(1), pp. 68–82. doi: 10.1080/09613210701446325.
- Chow, T. T., Zhang, G. Q., Lin, Z. and Song, C. L. (2002) 'Global optimization of absorption chiller system by genetic algorithm and neural network', *Energy and Buildings*, 34, pp. 103–109. doi: 10.1016/S0378-7788(01)00085-8.
- Conraud-bianchi, J. (2008) *A Methodology for the Optimization of Building Energy, Thermal, and Visual Performance*.
- Galasiu, A. D. and Veitch, J. A. (2006) 'Occupant preferences and satisfaction with the luminous environment and control systems in daylight offices: a literature review', *Energy and Buildings*, 38(7), pp. 728–742. doi: 10.1016/j.enbuild.2006.03.001.
- Hecht-Nielsen, R. (1989) 'the Backpropagation Neural Network', *Processing*, 1, pp. 593–605. doi: 10.1109/IJCNN.1989.118638.
- Heschong, L., Wright, R. L. and Okura, S. (2002) 'Daylighting Impacts on Human Performance in School', *Journal of the Illuminating Engineering Society*, 31(2), pp. 101–114. doi: 10.1080/00994480.2002.10748396.
- Hu, J., Olbina, S. and Asce, A. M. (2014) 'Simulation-Based Model for Integrated Daylighting System Design', *Journal of Computing in Civil Engineering*, 28. doi: 10.1061/(ASCE)CP.1943-5487.0000336.
- Jain, A. K., Mao, J. and Mohiuddin, K. M. (1996) 'Artificial Neural Networks: A Tutorial', *IEEE Computer*, 29(3), pp. 31–44.
- Janjai, S. and Plaon, P. (2011) 'Estimation of sky luminance in the tropics using artificial neural networks: Modeling and performance comparison with the CIE model', *Applied Energy*. Elsevier Ltd, 88(3), pp. 840–847. doi: 10.1016/j.apenergy.2010.09.004.
- Joe, C. (2009) *Build Neural Network With MS Excel, XLPert Enterprise*.
- Kazanasmaz, T., Gunaydin, M. and Binol, S. (2009) 'Artificial neural networks to predict daylight illuminance in office buildings', 44, pp. 1751–1757. doi: 10.1016/j.buildenv.2008.11.012.
- Lopez, G. and Gueymard, C. A. (2007) 'Clear-sky solar luminous efficacy determination using artificial neural networks', *Solar Energy*, 81(7), pp. 929–939. doi: 10.1016/j.solener.2006.11.001.
- Magnier, L. and Haghighat, F. (2010) 'Multiobjective optimization of building design using TRNSYS simulations, genetic algorithm, and Artificial Neural Network', *Building and Environment*. Elsevier Ltd, 45(3), pp. 739–746. doi: 10.1016/j.buildenv.2009.08.016.
- McNeil, A. and Lee, E. S. (2012) 'A validation of the Radiance three-phase simulation method for modelling annual daylight performance of optically complex fenestration systems', *Journal of Building Performance Simulation*, 6(1), pp. 24–37. doi: 10.1080/19401493.2012.671852.
- Neto, A. H. and Fiorelli, F. A. S. (2008) 'Comparison between detailed model simulation and artificial neural network for forecasting building energy consumption', *Energy and Buildings*, 40(12), pp. 2169–2176. doi: 10.1016/j.enbuild.2008.06.013.
- Pattanasethanon, S., Lertsatitthanakorn, C. and Atthajariyakul, S. (2008) 'An accuracy assessment of an empirical sine model, a novel sine model and an artificial neural network model for forecasting illuminance / irradiance on horizontal plane of all sky types at Mahasarakham, Thailand', 49, pp. 1999–2005. doi: 10.1016/j.enconman.2008.02.014.
- Pollock, M., Roderick, Y., Mcewan, D. and Wheatley, C. (2009) 'Building Simulation as an Assisting Tool in Designing an Energy Efficient Building: A Case Study', in *Eleventh International IBPSA Conference*. Glasgow, Scotland, pp. 1191–1198. Available at: [http://www.ibpsa.org/proceedings/bs2009/bs09\\_1191\\_1198.pdf](http://www.ibpsa.org/proceedings/bs2009/bs09_1191_1198.pdf) (Accessed: 17 May 2017).
- Reinhart, C. F., Mardaljevic, J. and Rogers, Z. (2013) 'Dynamic Daylight Performance Metrics for Sustainable Building Design', *The journal of the illuminating Engineering Society of North America*, 3(1), pp. 7–31. doi: 10.1582/LEUKOS.2006.03.01.001.
- Reinhart, C. F. and Walkenhorst, O. (2001) 'Validation of dynamic RADIANCE-based daylight simulations for a test office with external blinds', *Energy and Buildings*, 33(7), pp. 683–697. doi: 10.1016/S0378-7788(01)00058-5.
- Reinhart, C. F. and Walkenhorst, O. (2001) 'Validation of dynamic RADIANCE-based daylight simulations for a test office with external blinds', *Energy and Buildings*, 33(7), pp. 683–697. doi: 10.1016/S0378-7788(01)00058-5.
- Reinhart, C. and Fitz, A. (2006) 'Findings from a survey on the current use of daylight simulations in building design', *Energy and Buildings*, 38(7), pp. 824–835. doi: 10.1016/j.enbuild.2006.03.012.

- Rojas, R. (1996) 'Neural networks: a systematic introduction', *Neural Networks*, p. 502. doi: 10.1016/0893-6080(94)90051-5.
- Simbrain* (2017). Available at: <http://www.simbrain.net> (Accessed: 1 May 2017).
- Suykens, J. A. K., Vandewalle, J. P. and De Moor, B. L. (2012) *Artificial neural networks for modelling and control of non-linear systems*. Springer Science & Business Media.
- Wong, S. L., Wan, K. K. W. and Lam, T. N. T. (2010) 'Artificial neural networks for energy analysis of office buildings with daylighting', *Applied Energy*. Elsevier Ltd, 87(2), pp. 551–557. doi: 10.1016/j.apenergy.2009.06.028.
- Zhao, H. X. and Magoulès, F. (2012) 'A review on the prediction of building energy consumption', *Renewable and Sustainable Energy Reviews*. Elsevier Ltd, 16(6), pp. 3586–3592. doi: 10.1016/j.rser.2012.02.049.
- Zhou, L. and Haghighat, F. (2009) 'Optimization of ventilation system design and operation in office environment, Part I: Methodology', *Building and Environment*. Elsevier Ltd, 44(4), pp. 651–656. doi: 10.1016/j.buildenv.2008.05.009.
- Zhou, S. and Liu, D. (2015) 'Prediction of Daylighting and Energy Performance Using Artificial Neural Network and Support Vector Machine', *American Journal of Civil Engineering and Architecture*, Vol. 3, 2015, Pages 1–8, 3(3A), pp. 1–8. doi: 10.12691/AJCEA-3-3A-1.

# BIM-based analysis and evaluation of the integration of transparent solar panels in existing buildings facades: Case of Educational buildings

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**Abstract:** The energy consumption in buildings is responsible for roughly 40% of the total energy use in the European Union. The European Commission recently pledged to cut the annual consumption of primary energy by 20% by 2020. The emerging Building Information Model (BIM), as a shared knowledge resource during a building's life cycle, can be used as a basis for building energy management.

The paper aims to retrofit an existing building glass facade with transparent solar panels, to increase the energy production of the building. Using the 6D BIM data as an input of the existing situation of energy consumption, building envelop and pattern of usage, an accurate estimation can be established regarding the percentage of the annual energy savings, and thus be able to evaluate the effectivity of this approach.

The concluded work aims to analyse the configuration of semi-transparent PV panels, in terms of area and placement, to replace the normal glass panels in an existing building under retrofit operations to offset a part of the building's energy consumption. The process is based on determining the optimum value of annual electric energy generation that can be provided with semi-transparent solar panels per square meter [kWh/m<sup>2</sup>], from the pool of possible configurations of solar panels, based on the annual solar insolation per unit of the glass parts of the façade and the Return Of Investment (ROI). In the case study, the effect of self-shading, shading from adjacent buildings, and shading from adjacent trees and landscape elements will be taken into consideration.

Autodesk Revit and Dynamo are used for the modelling, analysis, and optimization procedure.

**Keywords:** Energy retrofit, 6D BIM, Educational Buildings, Building integrated Photovoltaics

## 1. Introduction

### 1.1 Energy retrofitting of existing buildings

Buildings consume a lot of energy, as buildings' energy consumption accounts for approximately 40% of total energy use and 36% of the total CO<sub>2</sub> emission in the European Union (Zhao & Magoulès 2012). This is particularly true for industrialized countries such as Germany, which from an engineering perspective, has a great potential to reduce its energy consumption by means of retrofitting existing buildings (Achtnicht & Madlener 2014). An energy retrofit can be defined as the physical or operational change in the building itself, its equipment, or its occupants' behaviour to reduce energy consumption (Jafari & Valentin 2017). One approach to reduce the net energy consumption is to utilize the building's resources to generate electricity, the most predominant approach to do so being the Building Integrated Photovoltaics (BIPV). BIPV modules should fit into the building structure, and when used in building facades, the resulting PV module is perceived as a standard glass pane and can be integrated into every facade (Benemann et al. 2001). These Facade-Integrated solar panels gain a special importance in the case of retrofitting existing buildings, where the building appearance and architectural identity needs to be preserved, and alterations to the building design should be kept minimal.

### ***1.2 Facade-Integrated semi-transparent solar panels***

Semi-transparent solar panels, differing from conventional PV, allows the solar radiation to penetrate the panel. Besides generating electricity, they give the buildings the advantage of natural space heating during winter and increased indoor illuminance from daylighting (Wong et al. 2008). There exist generally 3 types of such panels currently in the market (Hwang et al. 2012):

- Monocrystalline silicon PV cell (High price, Low visibility and Efficiency 14–16%)
- Multi-crystalline silicon PV cell (High price, Low visibility and Efficiency 12–15%)
- Amorphous silicon PV cell (Low price, High visibility and Efficiency 6-8%)

(Hwang et al. 2012), (Miyazaki et al. 2005), and (de Boer & van Helden 2001) examined the potential of integrating semi-transparent solar panels in office buildings. However, the analyses assumed great liberty in examining different configurations and setups for these panels which is inconsistent with the case of existing buildings where very minimal alterations on buildings' exteriors is allowed. Furthermore, comparative analyses were made using estimated energy consumption data based on computer simulations rather than using actual building data (apart from the first reference).

### ***1.3 Integrating 6D BIM data with BIM-based analysis***

6D BIM (sixth-dimensional Building Information Modelling) refers to the post-construction, facility management phase (FM) of the building, where BIM is primarily oriented to improve FM efficiency (Nicał & Wodyński 2016). Using actual FM data regarding energy consumption from existing buildings, designers can perform very accurate analysis by integrating this data with BIM models and BIM-based analyses. This is profoundly enhanced by the wealth of information provided in a BIM model and the computational capabilities of BIM software to be able to iteratively perform model-based analyses and get instant, accurate results. In the case of Facade-Integrated solar panels, designers can compare between the actual building's energy consumption and the expected energy outcome from the panels to evaluate the feasibility of installing such panels. Furthermore, estimations can be made regarding the optimal positions for installing the panels to achieve the highest return of investment.

### ***1.4 Retrofitting Educational Buildings***

International Energy Agency (IEA) member countries agreed that educational buildings such as kindergartens, schools and universities have similarities in the design, operation and maintenance then the agency published a report that indicates that these buildings types have similarities in high energy consumptions and the necessity to retrofit many buildings within this sector (Barton 2007). A study for buildings stock in Europe have concluded that 17% of Non-residential building stock in EU are Educational buildings and one third of the of all EU citizens spend their days in these buildings (Bogdan Atanasiu 2011). Thus, one of the roads to sustainable buildings in EU to retrofit these buildings and minimise its consumption of Energy.

## **2. Research objectives**

The purpose of this paper is to evaluate the potential of electric energy production through the installation of semi-transparent solar panels instead of normal glass windows in an existing building's facade. Furthermore, the research seeks to outline a workflow to determine the ideal placement, configuration and percentage of solar panel coverage of such panels that yield the shortest payback period. The outlined analyses are as follows:



1. A solar insolation analysis on the 4 existing building facades, in addition to the internal courts, to determine the amount of solar energy falling on the window surfaces in a year.
2. Calculations to determine the energy generation potential throughout the year for windows' panels when replaced with semi-transparent panels of various efficiencies and transparency values.
3. Calculations to determine the Payback Period for the solar panels' installation investment.
4. An analysis of the estimated electricity production from the solar panels against the energy consumption values as obtained from the database of the building's Energy consumption.

### **3. Research methodology**

#### ***3.1 Choice of the case study***

The TU Berlin campus buildings have been overgo a lot of modifications through years, and the university has decided to renovate its buildings and try to make a zero energy buildings, to minimise the consumption of energy overall, one of the main reasons to choose the case study of the main building (Hauptgebäude) of TU Berlin is that the building is considered the oldest (1884) and with an additional building attached to the entrance finished by 1951, and this pour into the goal of the research of retrofitting the old buildings and specially that the building have been retrofitted before using the ordinary techniques of rehabilitation and adding new buildings (see Figure 1).



Figure 1. The front of TU Berlin building H showing the new northern façade. (author)

#### ***3.2 6D BIM Input data for simulation***

Data about electricity price per kWh in Berlin was obtained from the statistical office of the European Union (Eurostat) (Eurostat 2016). Input data of actual energy consumption is imported from 6D BIM database of the building and it is verified as from 26th of June 2017. A market study has been done for varieties of semi-transparent Crystalline and Amorphous solar panels to determine the price of installation, efficiency, and transparency for these 2 types. Values for all input data are summarized in Table 1.

Table 1. Input data for analysis and values for simulation

### Input Data

Annual energy consumption	3688224 KWh
Energy cost per KWh	0.3 euros ( 5% annual increase)
Crystalline panels efficiency	15%
Cost per sqm crystalline panels	147.06 euros
Amorphous panels efficiency	8%
Cost per sqm amorphous panels	97.16 euros

### 3.3 BIM model level of development

Before starting the process of the simulation a BIM model have been developed and a strategy for modelling and simulation has been established, Level Of Development (LOD) have been accredited for use of LOD 200, due to its light details for simulation (Eastman et al. 2011) The AIA suggest that the LOD framework recognises that different elements of the project will develop at different rates and '*...allows the Project Participants to efficiently communicate to one another the extent to which a Model Element has been developed ... It also allows the Project Participants to communicate the extent to which a Model element may be used and relied on...*' (AIA 2013).

For LOD 200 and according to AIA BIM standards, the model element is graphically represented within the Model as a generic system, object, or assembly with approximate quantities, size, shape, location, and orientation. Non-graphic information may also be attached to the Model Element. (American Institute of Architects 2013). The surrounding environment of the model have been degraded to the least details, that's because, for the purposes of the solar insolation simulation, only an approximation of the shadow casted by these surroundings is needed (trees and surrounding buildings were modelled as blocks forms (see Figure 2).

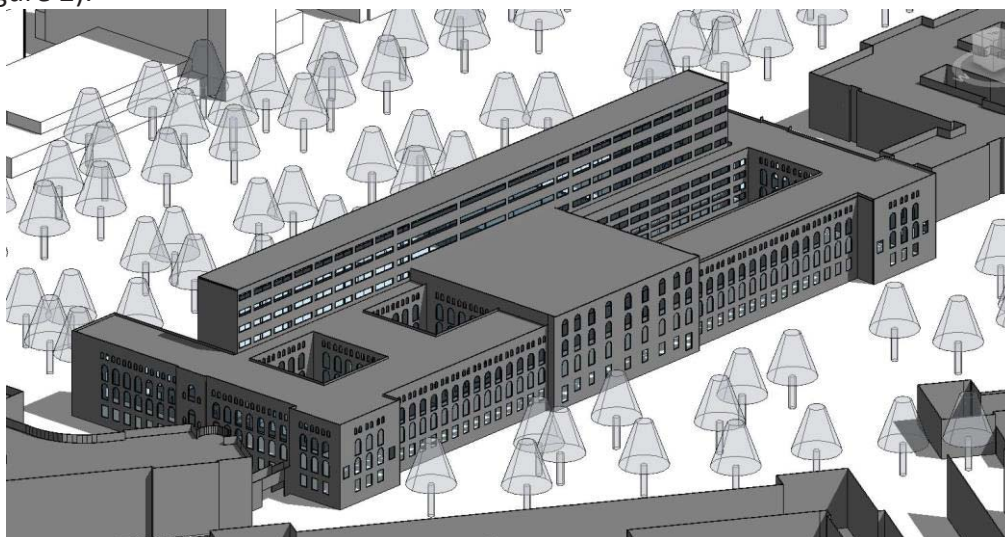


Figure 2. LOD 200 model of the case study Building.

### 3.4 Simulation and Analysis

To build the BIM model of the case study, “Autodesk Revit” (version 2018.1) was used, since it comes equipped with a host of computational capabilities via “Autodesk Dynamo”. “Dynamo” (version 1.3) and its plugin “Solar analysis for Dynamo” (version 1.2.2) were used for the solar insolation analysis and all the estimations established throughout this research. An overview of the Dynamo graph could be seen in Figure 3. Inputs for the analysis included the building model elements from the BIM model to calculate shading and solar insolation. Inputs also included panel efficiency and price, electricity price and annual energy consumption. Outputs of the analysis included estimated annual power generation from the solar panels, percentage of energy generated from the total energy consumption, estimated cost of installation, and projected payback period for both types of the solar panels. The analysis results are detailed in the following section.

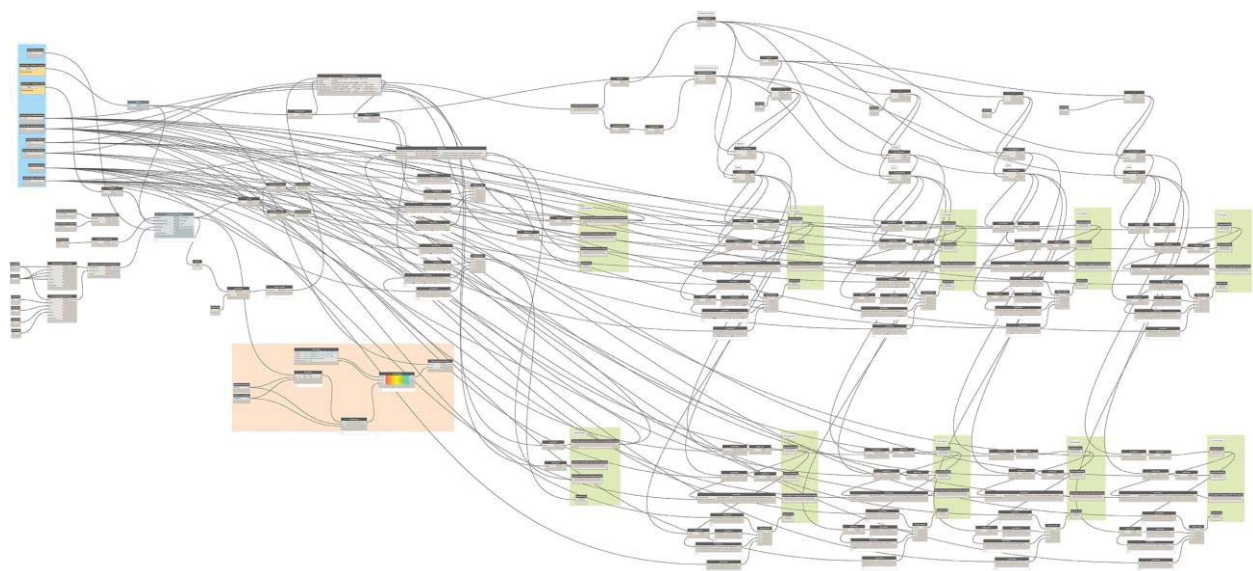


Figure 3. Autodesk dynamo algorithm for the model simulation

## 4. Analysis and results

The model analysis has been divided into 5 analyses (four elevations and courtyards) to get the optimal behaviour of each facades the courtyards elevations have been separated from the simulation. The courtyards elevations have been simulated all together.

The simulation was over semi-transparent Crystalline and Amorphous solar panels, then the dynamo gets the simulated data for 100% coverage and replacement of the glass with the solar panels, then calculation of the (75% - 60% - 45% - 30%) highest yielding panels energy production.

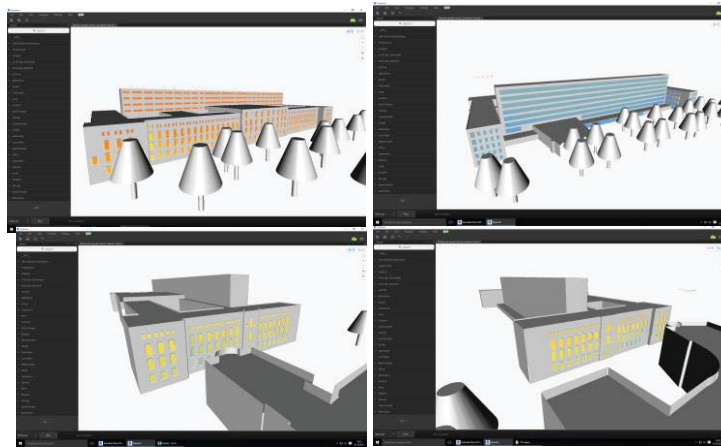


Figure 4. Simulation screenshot

#### 4.1 North elevation simulation

The north elevation was the least elevation of energy production it can produce of 107884 KWh/year with the Crystalline panels and 57538 KWh/year with the Amorphous panels, with a total area of semi-transparent solar panel of 4394.6 m<sup>2</sup>, the percentage of contribution of the façade to the total energy consumption of the building can reach 2.9% with the Crystalline panels and 1.56% with the Amorphous panels with a Return of Investment 15 and 17 years respectively. The analysis for the (75% - 60% - 45% - 30%) highest yielding panels energy production can be found in Figure 5.

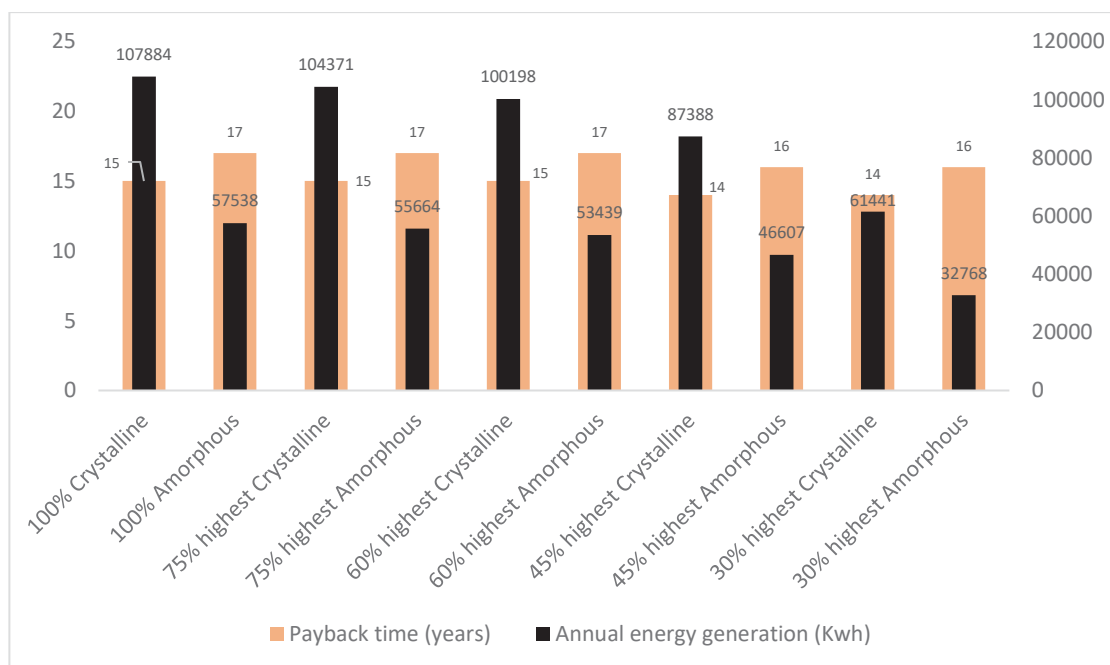


Figure 5. Simulation Result for Northern elevation

#### 4.2 Southern elevation simulation

The Southern elevation was the highest elevation of energy production it can produce of 144171 KWh/year with the Crystalline panels and 768910 KWh/year with the Amorphous panels, with a total area of semi-transparent solar panel of 1867.5 m<sup>2</sup>, the percentage of contribution of the façade to the total energy consumption of the building can reach 3.9% with the Crystalline panels and 2.1% with the Amorphous panels with a Return of Investment



6 and 7 years respectively. The analysis for the (75% - 60% - 45% - 30%) highest yielding panels energy production can be found in Figure 6.

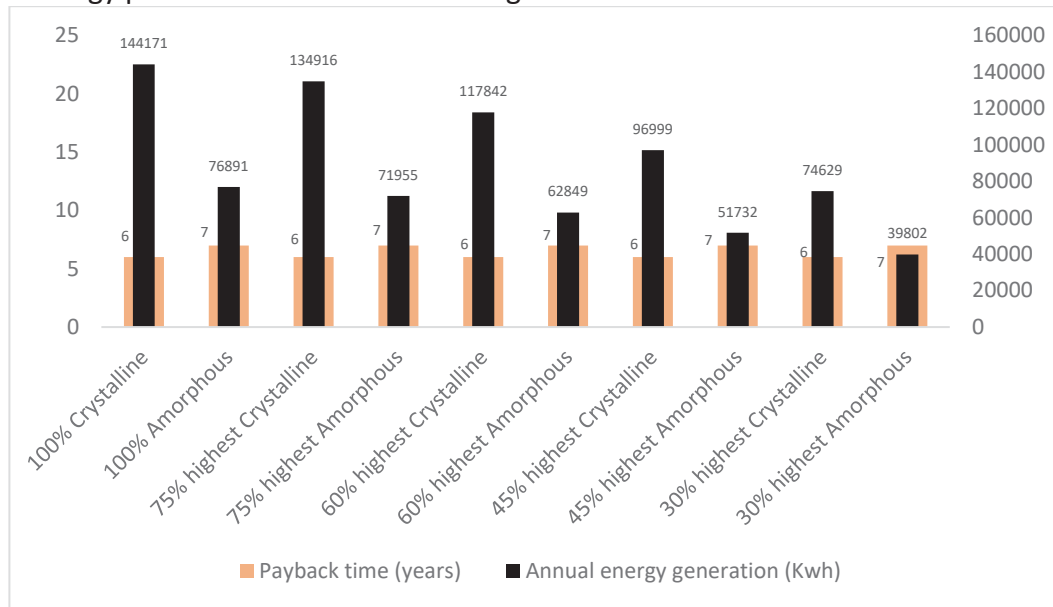


Figure6. Simulation Result for Southern elevation

#### 4.3 Western elevation simulation

The Western elevation was the highest elevation of energy production comparing to the other wing elevation it can produce of 19783 KWh/year with the Crystalline panels and 10550 KWh/year with the Amorphous panels, with a total area of semi-transparent solar panel of 402.8 m<sup>2</sup>, the percentage of contribution of the façade to the total energy consumption of the building can reach 0.5% with the Crystalline panels and 0.3% with the Amorphous panels with a Return of Investment 9 and 10 years respectively. The analysis for the (75% - 60% - 45% - 30%) highest yielding panels energy production can be found in Figure 7.

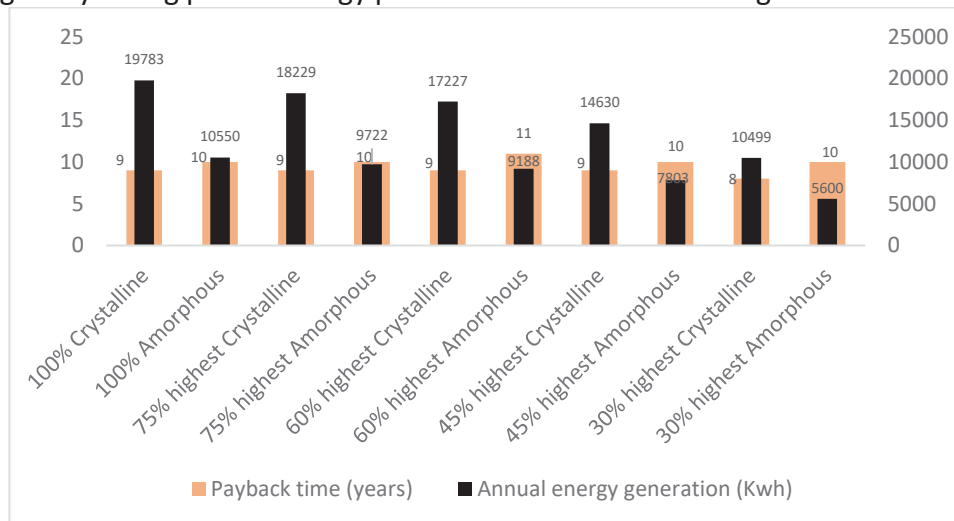


Figure 7. Simulation Result for Western elevation

#### 4.4 Eastern elevation simulation

The east elevation was the slightly less than the western elevation of energy production due to the surrounding building which is blocking the sun, it can produce of 18447 KWh/year with the Crystalline panels and 9838 KWh/year with the Amorphous panels, with a total area of semi-transparent solar panel of 408.2 m<sup>2</sup>, the percentage of contribution of the façade to the total energy consumption of the building can reach 0.5% with the Crystalline panels and 0.3%



with the Amorphous panels with a Return of Investment 9 and 11 years respectively. The analysis for the (75% - 60% - 45% - 30%) highest yielding panels energy production can be found in Figure 8.

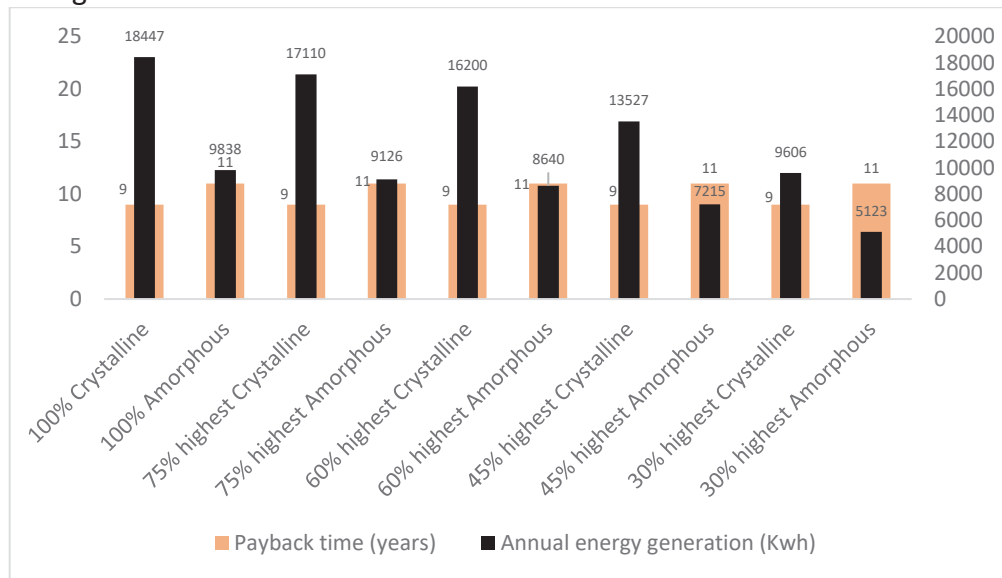


Figure 8. Simulation Result for Eastern elevation

#### 4.5 Courtyard elevation simulation

The courtyards elevations energy production was 59779 KWh/year with the Crystalline panels and 31882 KWh/year with the Amorphous panels, with a total area of semi-transparent solar panel of 1447.8 m<sup>2</sup>, the percentage of contribution of the façade to the total energy consumption of the building can reach 1.6% with the Crystalline panels and 0.9% with the Amorphous panels with a Return of Investment 10 and 12 years respectively. The analysis for the (75% - 60% - 45% - 30%) highest yielding panels energy production can be found in Figure 9.

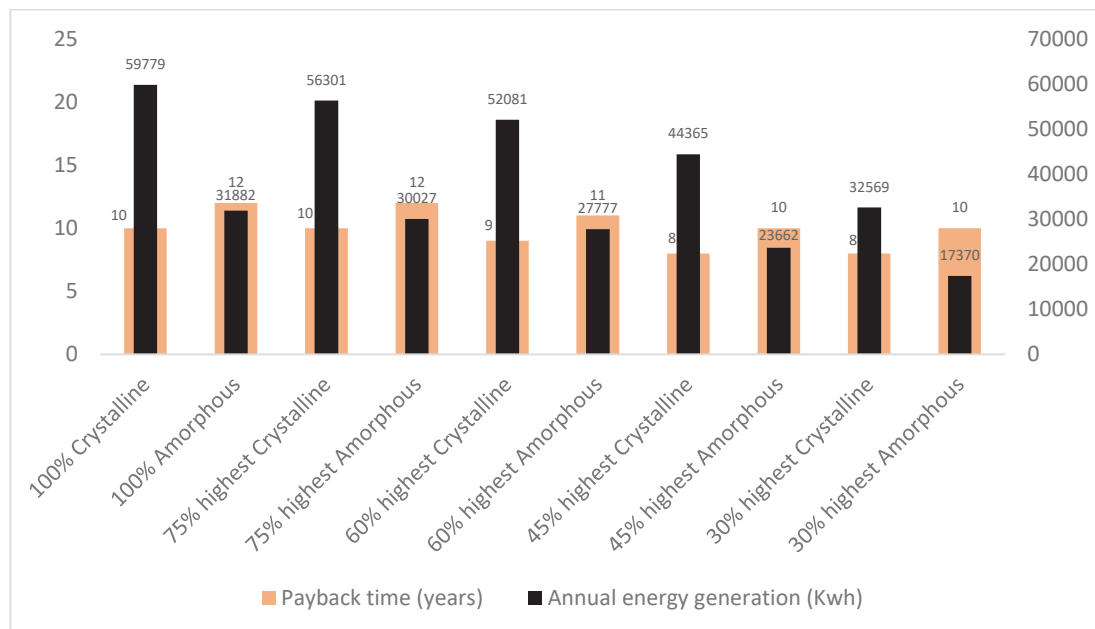


Figure 9. Simulation Result for Courtyards elevations

#### 4.6 The amount of energy produced per meter square

After the simulation of the facades it have been noticed that the northern façade produces the least energy but due to its design with glass windows it comes to a consideration to produce a close amount of energy to the second least façades, table 2 shows the crystalline panels outcome for every façade and how much KWh/m2 will each façade produces per year.

Table 2. output of every façade simulation and the amount of energy produced per m2 for crystalline panels

<b>Crystalline panels</b>	<b>Northern Façade</b>	<b>Southern Façade</b>	<b>Western Façade</b>	<b>Eastern Façade</b>	<b>Courts</b>
<b>Annual energy generation (Kwh)</b>	107884.0	144171.0	19783.0	18447.0	59779.0
<b>Available surface area (m2)</b>	4394.6	1867.5	402.8	408.2	1447.8
<b>kwh/m2/year</b>	24.5	77.2	49.1	45.2	41.3

The amorphous panels produces less energy than the crystalline panels due to the efficiency of the panel type simulated and table 3 shows the amorphous panels outcome for every façade and how much KWh/m2 will each façade produces per year.

Table 3. output of every façade simulation and the amount of energy produced per m2 for amorphous panels

<b>Amorphous panels</b>	<b>Northern Façade</b>	<b>Southern Façade</b>	<b>Western Façade</b>	<b>Eastern Façade</b>	<b>Courts</b>
<b>Annual energy generation (Kwh)</b>	57538.0	76891.0	10550.0	9838.0	31882.0
<b>Available surface area (m2)</b>	4394.6	1867.5	402.8	408.2	1447.8
<b>kwh/m2/year</b>	13.1	41.2	26.2	24.1	22.0

## 5. Conclusion

Following the rising interest in Germany to pursue greener, more sustainable sources of energy, there is real potential in retrofitting older existing buildings either to save energy consumption or to compensate for part of this consumption by generating electricity. The challenge with existing buildings however, is the fact that design alterations should be kept minimal. The research examined the idea of integrating semi-transparent solar panels in the building facades instead of regular glass panels. Analyses were made for a case study on the main building of TU Berlin, simulating solar insolation on the building's facade and courts. The main research findings are as follows:

1. The approach outlined in this research can prove to provide a significant percentage of the building's energy consumption without sacrificing aesthetic value. In the best cases, up to 9.4% of the total consumption could be generated from the solar panels.
2. The ROI to the retrofits can reach 6 years in the best cases which mean short time for return of investment regarding the two types of semi-transparent solar panels.
3. Optimisation of different types of semi-transparent solar panels can be made to optimise the least time ROI and highest energy production.

Future work will include other varieties of Crystalline and Amorphous solar panels, as well as further case studies of buildings from the TU Berlin Campus. Work will also investigate the effect of these panels on natural lighting and daylight factor in the interior spaces of the buildings, as compared to existing regular glass panels.

## 6. Acknowledgements

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## 7. References

- Achtnicht, M. & Madlener, R., 2014. Factors influencing German house owners' preferences on energy retrofits. *Energy policy*, 68, pp.254–263.
- AIA, 2013. *Guide, Instructions and Commentary to the 2013 AIA Digital Practice Documents*, The American Institute of Architects.
- American Institute of Architects, 2013. *The Architect's Handbook of Professional Practice*, John Wiley & Sons.
- Barton, R., 2007. *Technical Synthesis Report: Retrofitting in Educational Buildings: Energy Concept Adviser for Technical Retrofit Measures*, ECBCS. Available at: <http://www.ecbcs.org/annexes/annex36.htm>.
- Benemann, J., Chehab, O. & Schaar-Gabriel, E., 2001. Building-integrated PV modules. *Solar Energy Materials & Solar Cells*, 67(1-4), pp.345–354.
- de Boer, B.J. & van Helden, W.G.J., 2001. PV MOBI, PV Modules Optimised for Building Integration, Bogdan Atanasiu, 2011. *EUROPE'S BUILDINGS UNDER THE MICROSCOPE: A country-by-country review of the energy performance of buildings* Chantal Despret, Marina Economidou, Joana Maio, Ingeborg Nolte, Oliver Rapf, ed., Buildings Performance Institute Europe (BPIE).
- Eastman, C. et al., 2011. *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors*, John Wiley & Sons.
- Eurostat, 2016. *Energy statistics - natural gas and electricity prices*,
- Hwang, T., Kang, S. & Kim, J.T., 2012. Optimization of the building integrated photovoltaic system in office buildings—Focus on the orientation, inclined angle and installed area. *Energy and Buildings*, 46, pp.92–104.
- Jafari, A. & Valentin, V., 2017. An optimization framework for building energy retrofits decision-making. *Building and environment*, 115, pp.118–129.
- Miyazaki, T., Akisawa, A. & Kashiwagi, T., 2005. Energy savings of office buildings by the use of semi-transparent solar cells for windows. *Renewable Energy*, 30(3), pp.281–304.
- Nicał, A.K. & Wodyński, W., 2016. Enhancing Facility Management through BIM 6D. *Procedia Engineering*, 164, pp.299–306.
- Wong, P.W. et al., 2008. Semi-transparent PV: Thermal performance, power generation, daylight modelling and energy saving potential in a residential application. *Renewable Energy*, 33(5), pp.1024–1036.
- Zhao, H.-X. & Magoulès, F., 2012. A review on the prediction of building energy consumption. *Renewable and Sustainable Energy Reviews*, 16(6), pp.3586–3592.

# A Study on Emergency Departments' Design Topologies and its Impact on Wayfinding Utilizing Space Syntax Techniques

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**Abstract:** This paper aims assessing the achievement of preset objectives of Emergency Departments (EDs) in early design phase according to the change of topological aspect, which have an impact on the performance of medical staff and satisfaction of patients and their families. To justify design objectives of ED, Evidence-Based Design (EBD) at EDs was taken in consideration. EBD is a way of design through research, where data is gathered through an accumulative collection of solutions from existing hospitals to improve design decisions consequently, the emergency service outcomes. In order to benefit from these solutions in design phase, it is needed to quantitatively understand the impact of ED configuration-related solutions on various human behaviors. Wherefore Space Syntax techniques are utilized to quantitatively represent the strength of connections between spaces that are arranged to each other in a given configuration with respect to human behavior. Thus, utilizing Space Syntax analysis provides measures that allows predicting how far EDs design strategies/solutions could be attained from a very early stage, and which ED topology meets most of these strategies. Correspondingly, when it comes to critical departments such as Emergency Departments, it is important to study the effectiveness of Space Syntax techniques with respect to ED design strategies that were extracted from EBD in decision-making at the design phase. A comparison between syntactical measures obtained from analyzing different ED topologies in order to deduce the effect of spatial configuration in wayfinding as a strategy needed to be achieved in ED. As a result of the comparison, centralized ED topology has an improving impact on wayfinding prediction.

**Keywords:** Emergency Department, Evidence Based Design, Space Syntax, Wayfinding, Design assessment

## Introduction

The emergency department (ED) is considered the “front door” of a hospital, where approximately two thirds of patients enter a hospital (Morgareidge et al., 2014). Therefore, EDs are facing many problems that affect the delivery of medical service and satisfaction of patients. Crowding, long waiting and leaving before treatment complete are from the important issues that affect the capability of ED to sustain the same level of medical treatment. Without considering the increasing number of patients arriving ED every year due to the growing population that may cause last mentioned issues, the study addresses causes reduction of ED issues from the early design stage. It explores different ED topologies, which believed to have a significant impact on human behavior (medical staff and patients) then the whole medical performance of ED and caregiving.

Layout configuration in a given ED topology and its effects on users' behavior are the key factors in the design assessment, since every topological difference would have different impact on the behavioral outcomes, trying to clarify which ED topology will be mostly aligned with the preset objectives of ED design. These objectives were previously set through what is known Evidence-based design (EBD). Since design decision about the physical environment takes place with reference to credible research to attain the best possible outcomes (Cama, 2009). Post-Occupancy Evaluation (POE) of existing hospitals is a research approach that leads to a credible evidence about the built environment, helping the process of decision making at the early design process for new hospitals (van der Zwart and van der Voordt, 2015).

Center for Health Systems and Design (Texas A&M University) and the college of Architecture (Georgia Tech) emerged a literature review on EBD (Ulrich et al., 2008), they found up to 600 studies on how healthcare facility design can influence medical outcomes. The review mentioned design issues such as wayfinding, noise effects and ergonomics. Where it is argued that the use of EBD as a way to design or develop healthcare facilities with the best available solutions considering how the physical environment can affect the activities of patients, families, and staff (Ulrich et al., 2008).

### **Evidence-Based Design at Emergency Departments**

While most of EBD studies conducted on the most common departments in an entire hospital like nursing units, ICUs and operation theatres, just few studies explore the ED as a start to understand what design concerning issues that faces the medical and operational performance of ED and its clinical outcomes.

One of these studies came up with new strategies in ED design, Angela Mazzi wrote at Health Facilities Management online magazine an article about the new strategies in ED design, many of these strategies are operational which will not affect the performance until they have been applied in an existing ED, such as accentuating of all key decision points from outer to the ED entrance using signage, providing a welcoming entrance inside the department and eliminating the negative associations of waiting areas. On the other hand, there are strategies concerning the configuration of physical environment that can be applied at the early design stage and have an improving impact on the ED medical performance (Mazzi, 2015). In Mazzi's article, many important strategies affecting ED performance in design phase came to the fore: (1) Wayfinding to treatment areas considered as a key factor for a good ED design, where it's found that medical staff consume considerable time being confused from patient to give directions which by default reduces staff productivity and patient satisfaction (Peponis et al., 1990), (2) Scaling strategy, where lower-volume EDs operate more efficiently, (3) Door-to-doctor time is a measure of efficiency of ED performance, (4) A clear observation strategy, it's found that observation units can save time and money, decreasing number of admissions and reducing length of patients' stay, and also lead to a lower probability of subsequent inpatient admission (Lu, 2010).

An important question is, how these strategies that are only experienced by users in the existing buildings can be measured in design phase based on architectural configuration of ED? One method for ED design analysis that is often described and utilized is Space Syntax.

### **Space Syntax**

Space Syntax was firstly introduced at the University College London (UCL) through Bill Hillier and his colleagues. It is based on the assumption that human behavior and patterns of movement are directly affected by topological patterns of spatial setting of the built environment (Hillier and Hanson, 1984, Hillier and Iida, 2005).

The configuration of circulation network and the setting of the functional spaces generate a pattern of movement as people move within a building while performing their tasks (Hillier and Hanson, 1984). Space Syntax is a method that quantitatively represent the strength of spatial configuration of built environments. The spatial configuration is the arrangement of spaces and set of connections between them, which creates buildings and cities (Hillier and Hanson, 1984). Therefore, Space Syntax abstracts architectural spatial configuration into a network of nodes and links representing patterns of accessibility, visibility and circulation. Twenty years ago, most syntactical calculations of spatial relations in a



network were manually conducted. Nowadays computer based programs were developed enhancing the opportunity of investigating the complex spatial relations of spaces and quantitatively describing and visualizing spatial quality (Turner, 2007). Spatial quality was then visualized through using space syntax techniques, which focus on the interrelationships between spaces, sight lines, and visibility.

### **Space Syntax Implementation on Healthcare Design**

A growing body of research implementing Space Syntax techniques in healthcare settings even though being relatively new in the field of healthcare facility research. A review has been conducted by (Haq and Luo, 2012) about the application of basic syntactical measures that have been used to investigate the effect of built environments on the behavior of hospitals' users such as, wayfinding, privacy preferences, nurses' movement, and evacuation patterns in hospital buildings.

(Pachilova and Sailer, 2013) and (Sailer et al., 2013) also studied interrelationship between patients and caregivers by comparing two different outpatient clinics typologies using the axial step depth measure. They proposed that clear spatial separation of staff and patient areas might help in efficient and frequent communication among them. Also (Khan, 2014) investigated wayfinding, which has received reasonable attention in the application of Space Syntax, to understand patients' satisfaction and travel experience. In the designing phase of a new emergency department (Morgareidge et al., 2014) combined Space Syntax techniques with discrete event simulation in order to analyze the influence of spatial configuration on the efficiency of visual surveillance, movement, and communication. The study emphasized on the importance of using Space Syntax techniques to facilitate decision making at the early design phase, improving operational performance, and reducing capital costs. All researches have been applied Space Syntax are then representing a ground evidence of how Space Syntax techniques were utilized to help in design assessment of a healthcare facility and stand on the problems of certain configuration from an early design stage.

### **Analyzing Emergency Department Main Topologies and Their Impact on Emergency Services**

Contemporary design concepts of ED architectural layout can be grouped into three main shapes as shown in Figure 1, (a) Centralized "ballrooms", (b) Decentralized "pods" and (c) linear "inner- core" configurations (Zlim, 2010). Thirty years ago, Centralized layout was the mostly used model for ED design, where treatment rooms wrapped around a central working area. This allows clear observation and good surveillance of patients and facilitates controlling of the departments. As pressure on ED increased and as more departments switched to private treatment rooms (Ulrich et al., 2008), the functional limit of the centralized ED layouts was reached at 16 to 18 rooms. Any departments exceed that limit it do not allow staff to observe all patient treatment areas, and the size of the staff work area starts to become disproportionately large. One other alternative to this layout is the decentralized layout design, which consists of clusters of 8 to 12 treatment rooms together with a staff work area and connected to other clusters (Pods). This provides the opportunity for smooth staff mobility and balanced proportions between support space and treatment areas.

A third organizational concept is emerging as a design solution to increase capacity, facilitate expansion advantage and enhance staff efficiency. This linear (inner-core) layout organizes treatment rooms around a staff work area. Rooms has two entries, with patients

and family accessing the treatment rooms from a perimeter corridor. Staff work in decentralized zones supporting 10 to 12 treatment rooms (Zlim, 2010).

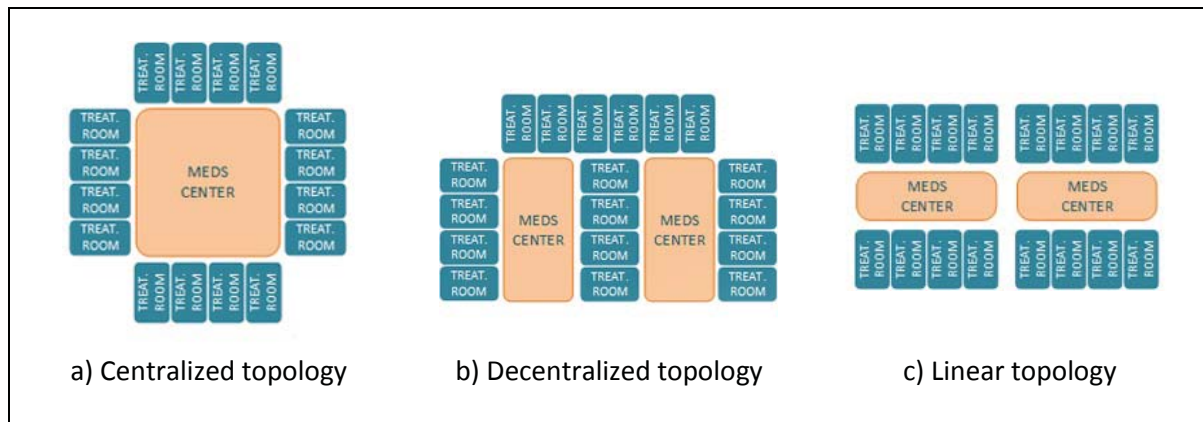


Figure 1 Main ED topologies (Zlim, 2010)

### ***Problem Definition and Selection Criteria of Case-Study Examples***

This study is about to measure the aspect of wayfinding from the ED entrance to the treatment rooms where main function of ED exists. Where wayfinding was mentioned before as one of the design strategies/objectives needed to be achieved for better ED Design according to EBD. The examples of EDs undergoing Space Syntax analysis are as following, (a) Centralized topology & (c) Linear topology: examples were mentioned at Health Facilities Management online magazine through an article for (Zlim, 2010), (b) Decentralized topology: ED at HealthAlliance of the Hudson Valley's (HVHA), New York, USA. (Souers, 2015). When trying to compare different entities through a common variable, it is important to make all other variables constant. Accordingly, criteria of selection were set as to get reasonable results and valid comparison. Therefore, it is important to select departments similar to each other from which the scale and main components of the department. From the scale point of view, the three selected examples are similar in scale where the staff area or medical support center serves almost the same range of treatment rooms. While from the department components point of view, the three examples consist of similar main components of walk in entrance, reception, ambulance entrance directed to treatment areas, and triage. Figure 2 & Table 1

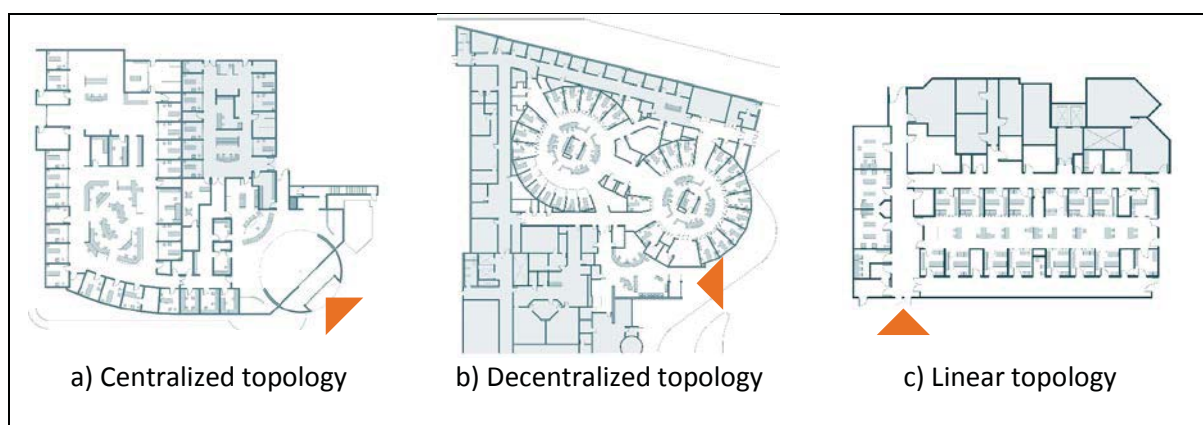


Figure 2 Case Study examples of the main ED topologies where Walk-In Entrances are marked by arrows.

Table 1 Design Characteristics of EDs in Present Study

Unit ID	Unit Type	Number of Rooms per support center	AREA
a	Centralized	16	1865 m <sup>2</sup>
b	Decentralized	14 / Medical Center	2200 m <sup>2</sup>
c	Linear	16	1000 m <sup>2</sup>

### Exploring Wayfinding Aspect from Walk-In Entrance to Treatment Area

The three examples undergo the same syntactical analysis as to predict the aspect of wayfinding, which is the key factor of efficient performance for ED and caregiving. Wayfinding importance in critical department such as ED laying on the idea of consuming the least steps and time to reach treatment area for medical care. In Space Syntax, wayfinding is quantified and numerically represented by a measure named *Step depth*. Step depth is the level of

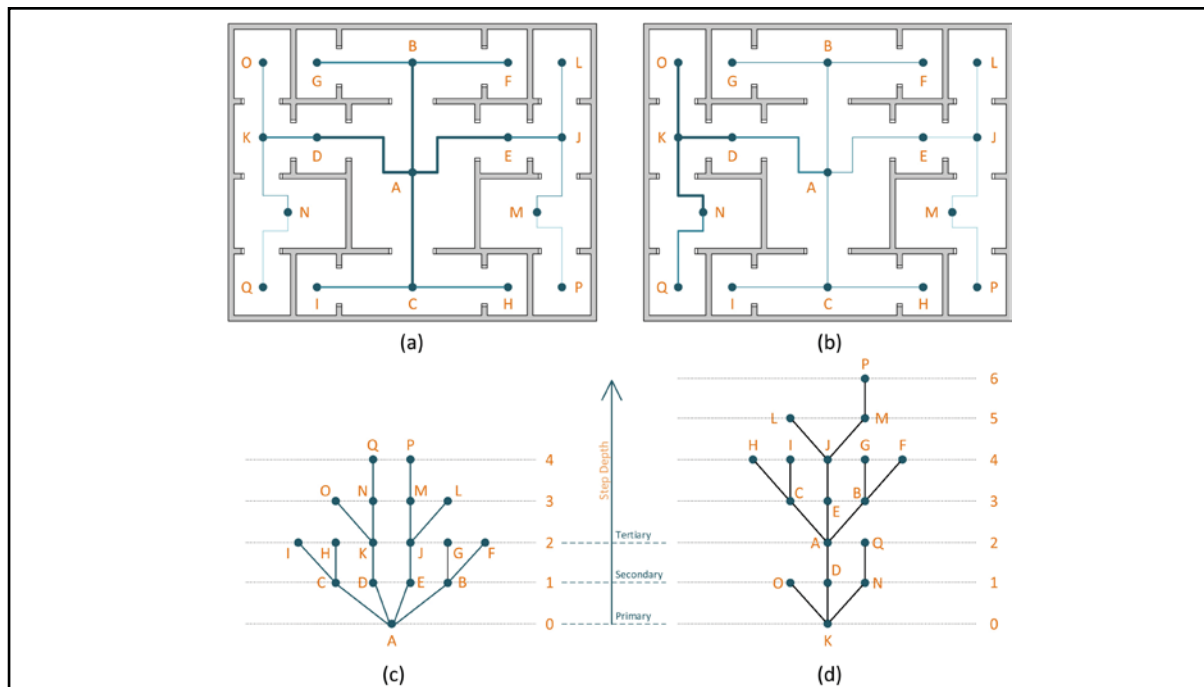


Figure 3 Illustration to clarify Step Depth and Justified Graph (Haq and Luo, 2012)

connection, in term of the number of turns along a path, which numerically represent the mutual relationship between all spaces (Hillier, 2007). As to facilitate understanding the concept of step depth, by referring to Figure 3a and Figure 3b a generic layout of some connected spaces, each space is represented by a node and a letter. In Space Syntax terms, the number of direct connections to other spaces is called *connectivity*. Thus, the connectivity values of spaces (A), (B), and (P) are 4, 2, and 1, respectively. After considering immediate connections, it can be seen that each space is increasingly connected to further spaces through a set of secondary, tertiary, and sequentially deeper spaces. For example, Space (J) is connected to Space (A) through spaces (E). Each level of connection is called *step depth*. Thus, space (A) is directly connected (i.e., one step depth) to spaces (B), (C), (D) and (E); it has secondary connections (i.e., two step depths) to spaces (F), (G), (H), (I), (J) and (K); it has tertiary connections (i.e., three step depths) to spaces (L), (M), (N) and (O), and so on, until all the other spaces are connected. In order to represent how deep the space; an illustration called *justified graph* is used as shown in Figure 3c and Figure 3d. A justified graph representing the depth of a particular space with respect to all spaces in the system, and by choosing space (A) and space (K) as a starting point to reach all spaces in the system. It's found

that all spaces can be reached from space (A) by 4 steps while from space (K) 6 steps are needed. By other words, step depth can quantify wayfinding from space (A) and (K), where space (A) is better than space (K) as a starting point to explore all the system (Haq and Luo, 2012). Therefore, a space with the least step depth is mostly the space that can be reached the fastest. A software developed to measure step depth named *Depthmap* (Turner et al., 2001) and used on the three examples of ED to analyze the aspect of wayfinding.

### **Reading and Comparing Results of Space Syntax Analysis**

In the case of emergency, it might be chaotic while receiving a case of trauma or any other patient that need a fast treatment. That is why it is continuously needed to enhance the wayfinding from entrances of ED, especially from walk-in entrance due to its publicity rather than ambulance entrance. As a result of the chaotic state as mentioned before, wayfinding not only needed to be enhanced for the patient but also for the staff member to facilitate the process of receiving a patient from the entrance towards the treatment area. Therefore, step depth would be measured through an axial map analysis starting from the axe from the walk-in entrance, and average mean step depth for the whole layout configuration at all examples.



Figure 4 Axial Step Depth from Walk-In Entrance at Centralized ED

By comparing the results of syntactical analysis on the mentioned ED topologies it's found that; Step depth at Centralized ED is the least where it took 1 to 2 steps/turns to reach the treatment area from the walk-in entrance Figure 4, while at Decentralized ED it took 1 to 3 steps/ turns to reach the treatment area Figure 5, on the other side Linear ED scored the highest step depth from walk-in entrance where it took 2 to 4 steps/turns to reach treatment area Figure 6. when step depth is read as a range it means that some parts of space can be reached by a value of step depth and the other parts by another value. However, at an emergency department, the effective value of step depth is the smallest value where the most important aspect is to reach any part of treatment area as fast as possible. Also by comparing the average mean step depth it's found that treatment area at Linear ED is the most reached from any other locations rather than the walk-in entrance, while treatment area at



Decentralized ED is difficult to reach from any other location rather than the walk-in entrance as shown in the comparison at Table 2.

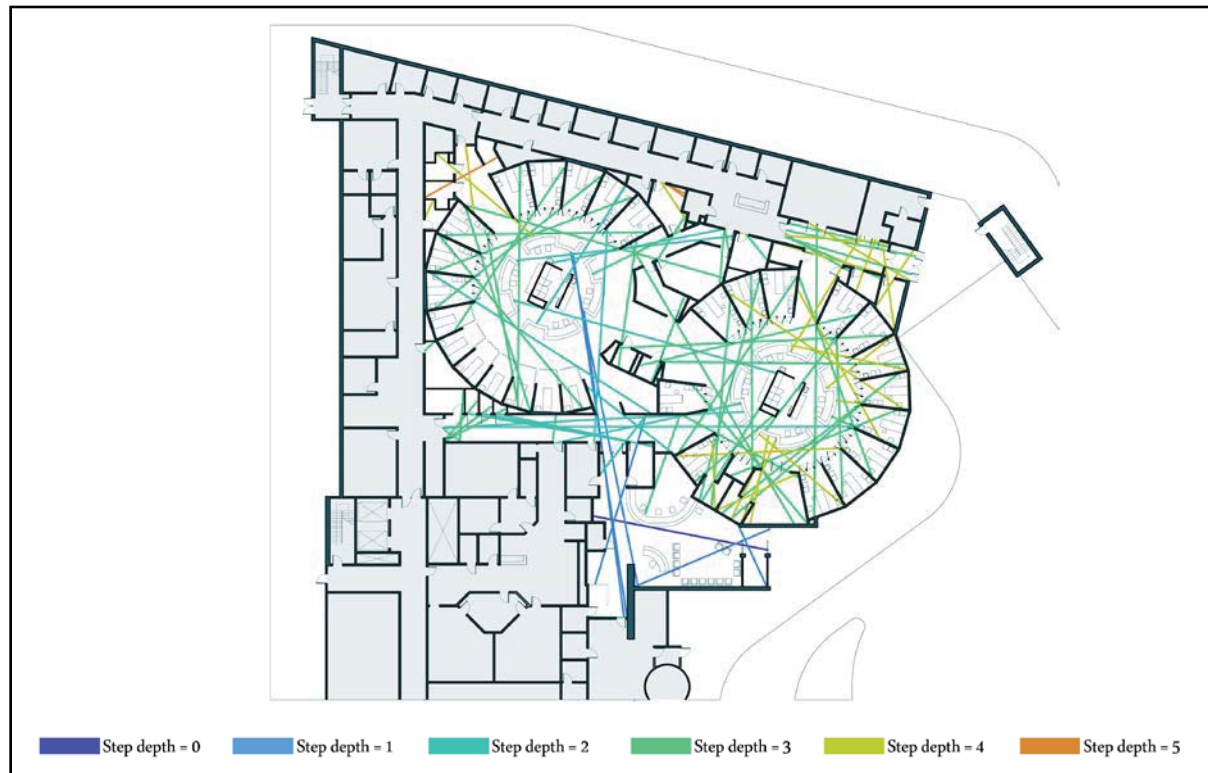


Figure 5 Axial Step Depth from Walk-In Entrance at Decentralized ED

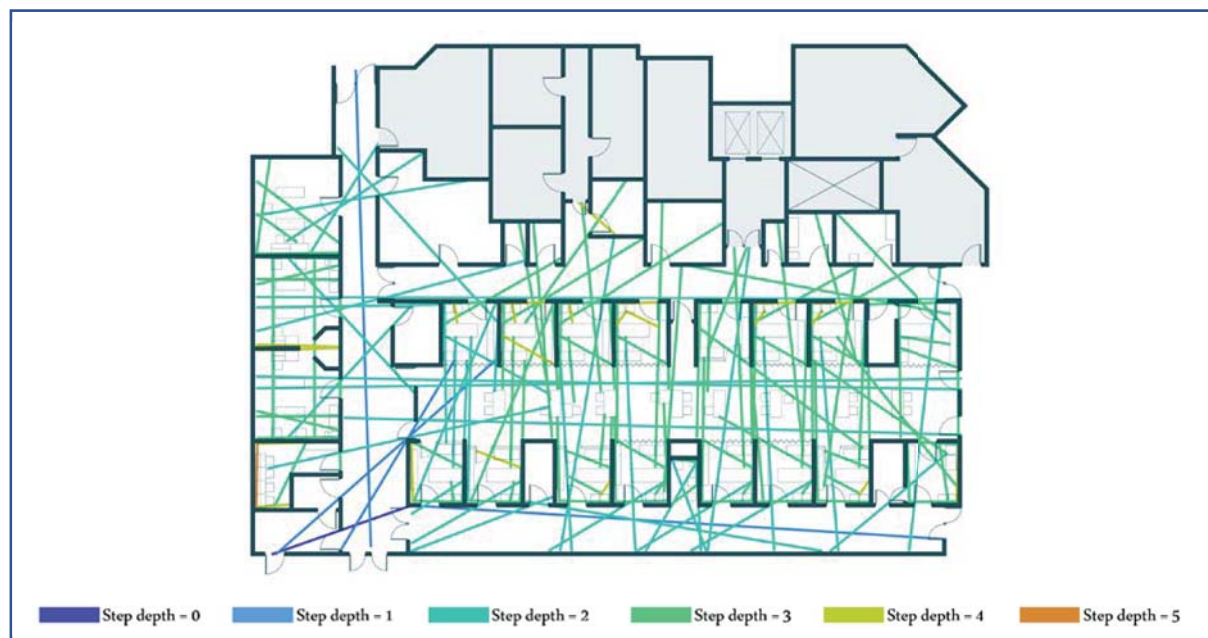


Figure 6 Axial Step Depth from Walk-In Entrance at Linear ED

Table 2 Comparison between Syntactical measures of ED Topologies

Unit ID	Unit Type	Step Depth	Average Mean Step Depth
a	Centralized	1-2	2.5
b	Decentralized	1-3	3
c	Linear	2-4	2.2



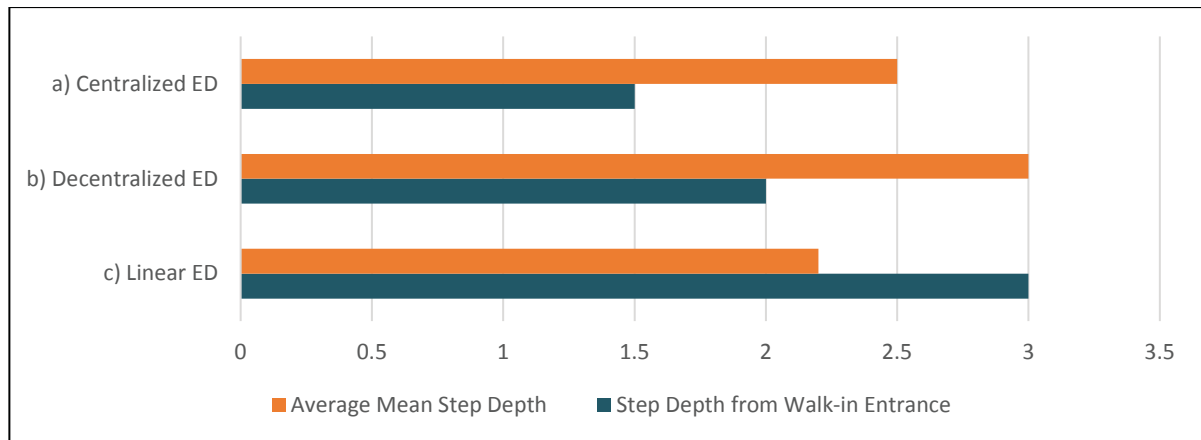


Figure 7 Wayfinding from Walk-In Entrance compared to Wayfinding from any other locations

### Discussion, Conclusion and Recommendations

By testing wayfinding strategy/objective according to EBD criteria, since wayfinding is measured in terms of number of steps to reach a space from a certain location. So, it helps understanding and expecting how users would behave and interact with particular spatial configuration. There are many other aspects that are not configurational but also can influence the perception and behaviour of the user among exploration and wayfinding in a building. Signage, coloured walls, accent features and furniture within space and etc, can enhance the prediction of wayfinding in complex settings like hospitals, by drawing visual information to user's perception, helping him in space exploration (Sadek and Shepley, 2016). However, for primarily design assessment in an early design stage, Space Syntax techniques can help us predict how users' behaviour would be, trying to raise the configurational quality which later has an effect on the operational phase. In a crowded place like Emergency Department, it's important to predict as much as possible how medical staff, patients and their families would behave in such spatial configuration, in order to get the best possible outcomes and caregiving.

In this study, Centralized ED has an improving impact than other ED topologies on wayfinding prediction, where it is easy to reach the treatment area from the walk-in entrance, and an intermediate connection from any other location (where it scored 2.5 of average mean step depth) in the system as shown at Figure 7. For further research, Step depth is one indicator of wayfinding in Space Syntax, another important indicator is the "Intelligibility" of the spatial configuration, which is the strength of the correlation between the local measure (i.e. connectivity) and the global one (i.e. integration). This measure has a role on how people understand the space and consequently how easy they could navigate through it. Also, it is recommended to measure other aspects based on the strategies extracted from EBD such as medical surveillance, Door-to-doctor time and privacy in terms of Space Syntax measures in order to draw complete image about how different topologies could attain all the strategies needed for better Emergency Department design.

### References

- CAMA, R. 2009. *Evidence-based healthcare design*, John Wiley & Sons.
- HAQ, S. & LUO, Y. 2012. Space Syntax in Healthcare Facilities Research: A Review. *HERD: Health Environments Research & Design Journal*, 5, 98-117.
- HILLIER, B. 2007. *Space is the machine: a configurational theory of architecture*, Space Syntax.

- HILLIER, B. & HANSON, J. 1984. *The Social Logic of Space*, Cambridge University Press.
- HILLIER, B. & IIDA, S. Network and psychological effects in urban movement. *COSIT*, 2005. Springer, 475-490.
- KHAN, N. Spatial correlates of patients' travel experience & satisfaction in hospital outpatient department. ARCC Conference Repository, 2014.
- LU, Y. 2010. Measuring the Structure of Visual Fields in Nursing Units. *HERD: Health Environments Research & Design Journal*, 3, 48-59.
- MAZZI, A. 2015. *New strategies in ED design: Handling demographic challenges while delivering efficient care* [Online]. Available: <http://www.hfmmagazine.com/articles/1451-new-strategies-in-ed-design> [Accessed 8-7 2017].
- MORGAREIDGE, D., HUI, C. & JUN, J. 2014. Performance-driven design with the support of digital tools: Applying discrete event simulation and space syntax on the design of the emergency department. *Frontiers of Architectural Research*, 3, 250-264.
- PACHILOVA, R. & SAILER, K. 2013. The effect of hospital layout on caregiver-patient communication patterns.
- PEPONIS, J., ZIMRING, C. & CHOI, Y. K. 1990. Finding the building in wayfinding. *Environment and behavior*, 22, 555-590.
- SADEK, A. H. & SHEPLEY, M. M. 2016. Space Syntax Analysis: Tools for Augmenting the Precision of Healthcare Facility Spatial Analysis. *HERD: Health Environments Research & Design Journal*.
- SAILER, K., PACHILOVA, R., KOSTOPOULOU, E., PRADINUK, R., MACKINNON, D. & HOOFWIJK, T. 2013. Proceedings of the Ninth International Space Syntax Symposium.
- SOUERS, D. A. 2015. *Hybrid "Ribbon Design" ED* [Online]. Optimus Architecture. Available: <http://optimusarchitecture.com/project/our-hybrid-ribbon-design-ed-for-healthalliance/> [Accessed 11 2017].
- TURNER, A. 2007. From axial to road-centre lines: a new representation for space syntax and a new model of route choice for transport network analysis. *Environment and Planning B: Planning and Design*, 34, 539-555.
- TURNER, A., DOXA, M., O'SULLIVAN, D. & PENN, A. 2001. From isovists to visibility graphs: a methodology for the analysis of architectural space. *Environment and Planning B: Planning and design*, 28, 103-121.
- ULRICH, R. S., ZIMRING, C., ZHU, X., DUBOSE, J., SEO, H.-B., CHOI, Y.-S., QUAN, X. & JOSEPH, A. 2008. A Review of the Research Literature on Evidence-Based Healthcare Design. *HERD: Health Environments Research & Design Journal*, 1, 61-125.
- VAN DER ZWART, J. & VAN DER VOORDT, T. J. M. 2015. Pre-Occupancy Evaluation of Patient Satisfaction in Hospitals. *HERD: Health Environments Research & Design Journal*, 9, 110-124.
- ZLIM, F. 2010. *Designing for emergencies: Integrating operations and adverse-event planning* [Online]. Available: <http://www.hfmmagazine.com/articles/1092-designing-for-emergencies> [Accessed 8-7 2017].

# Shape Memory Alloy Building Shells: A Zero Electricity Dynamic Shading System Simulation

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**Abstract:** In the 21st century, the energy sustainability era, climate adaptive building shells (CABS) became an appealing architectural application. Such appeal is due to the ability of such shells to move and react mechanically (macro-scale CABS) to external energy stimuli; which can control different building envelope aspects such as its thermal loads and daylight exposure. However, such moving ability intrinsically involves using sensor-actuator systems which use electric energy to move the envelope's components. Thus, for the sustainability trend, it is appealing to use a building envelope material that directly changes its form due to thermal loads (renewable solar energy) without electricity; shape memory alloys (SMAs).

Thus, the research focuses on simulating a two-way SMA (can remember two shapes) building envelope using Grasshopper tool (Ladybug and Honeybee plugins) upon two steps. First, simulating the SMA building envelope form change; the heat transfer equation –using solar thermal loads and dry bulb temperatures- is used to simulate a macro-scale form transformation of a Nickel Titanium Zirconium SMA (NiTiZr) southern building envelope panel monthly. Such simulation aims to showcase the potential form change of SMAs based on temperature changes without going into the technicalities of designing an exposed SMA spring actuator. Second, the amount of thermal loads upon a sample southern building envelope is calculated when applying an extra skin of the NiTiZr paneling. Such result is finally compared to a traditional static shading over sample selected days of the year.

The research's results aim to highlight a potential material application to explore; relevant to using renewable solar energy. Furthermore, the research concludes with an approach to use exposed SMA spring actuators to reach similar results to the simulation. Such approach can minimize the amount of SMAs to be used in envelopes compared to the NiTiZr panelling, while reaching similar zero electricity results.

**Keywords:** Climate Adaptive Building Shells, Thermal Loads, Macro-scale Simulation, Shape Memory Alloys, Nickel Titanium

## Introduction

### *Shape Memory Alloys in Form Changing Building Envelopes*

Form changing building envelopes and form changing building materials have been introduced based on the idea of reaction to external energy stimuli; climate adaptive building shells (CABS) (Loonen *et al.*, 2013). Such shells are usually reached using sensor-actuator systems that depend on the presence of smart materials within those devices; shape changing materials for actuating actions and different smart materials for sensing energy stimuli (Harris, 2002). However, the idea of implementing shape changing materials directly in the building envelope has not been researched extensively. One of the materials showing theoretical potential in such application is the nickel titanium (NiTi) two way shape memory alloy (SMA); such material has the property of changing its shape due to a change in temperature. In other words, this material can remember two shapes; i.e. during heating, the material starts its form change at austenite start temperature ( $A_s$ ) and ends at the austenite final temperature ( $A_f$ ), while when cooling, the material changes its form at martensite start ( $M_s$ ) and final ( $M_f$ ) temperatures which are usually lower than the austenite ones as shown in Figure 1 (Duerig and Pelton, 1994). These temperatures are controllable using the NiTi percentages, the type of additive materials, and the aging temperature and time of the material; where high temperature is applied for a certain

amount of time to let the material memorize a shape (Duerig and Pelton, 1994; Evirgen *et al.*, 2016).

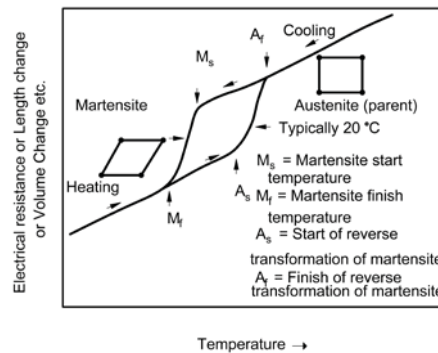


Figure 1 Typical SMA Heating and Cooling Cycle (Duerig and Pelton, 1994)

One of the few projects that introduced the concept of implementing NiTi SMA in the building envelope is Almidan Theatre in Heifa; only as a concept that has not been physically implemented. The case study promotes an implementation proposal of a shading system (louver like) in front of the western façade. NiTi is used as springs both in the physical implementation of the envelope, and in the actuators. This produces a passive system whose springs react to temperature as shown in Figure 2, and to overcome any explicit situations the springs can be overdriven actively according to the users' needs using spring shaped actuators (Lazarovich, Capeluto and Silverstein, 2015).

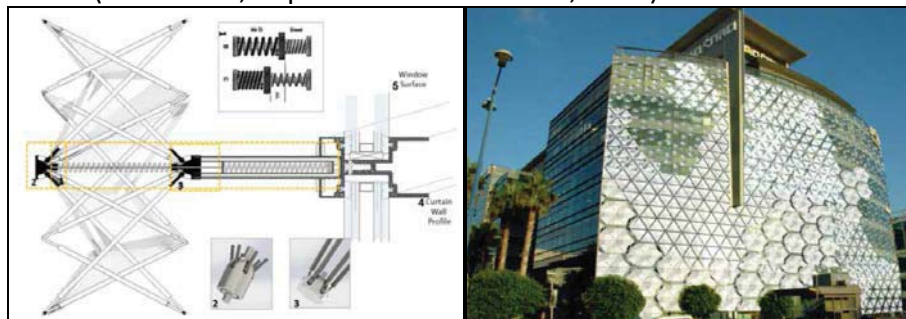


Figure 2, From Left to Right, Detailed Section of the Proposed Shading System, the Final Shape of the Western Building Envelope (Lazarovich, Capeluto and Silverstein, 2015)

### Shape Memory Alloys Simulation

The simulation history of SMAs has been highly dependent upon analyzing the complex thermal and mechanical behaviors of these materials. This started by using one dimensional simulation techniques to minimize the calculations as introduced by Tanaka *et al.* in 1986, Patoor *et al.* in 1988 and 1994 and Brinson in 1993 (Tanaka, Kobayashi and Sato, 1986; Patoor, Eberhardt and Berveiller, 1988, 1994; Patoor *et al.*, 2000). Reaching a three dimensional simulation introduced either the problem of lacking complete accuracy or having a large amount of computations (Gao, Huang and Brinson, 2000; Patoor *et al.*, 2000; Juhasz *et al.*, 2002). Thus different simulation approaches simplified 3-D forms into forms that can be regarded as 2-D or 1-D; such as wires which are arrayed to reach a 3-D resultant (Burton, Gao and Brinson, 2006). Burton D.S. *et al.* introduced such idea by using a 1-D calculation technique in a finite simulation approach over a 3-D self-healing SMA composite. Yet, up to the author's knowledge, no simplified macro-scale real-time simulation of SMA shape change in case of direct application upon the building envelope with its effect is present. Thus, no simulation of the effect of using such SMA skin upon the solar loads falling on the building envelope is present as well.

## Methods

### Shape Memory Alloy Shape Change Simulation

#### *Tools and Computational Method*

The simulation approach is based upon simplification; the simulation should reach real time results for SMA building envelopes and be accessible to architects during the design phase. Furthermore, a simple simulation should be reached for the effect of using SMA skins in comparison to fixed ones in terms of solar loads. Thus, first order cybernetics are introduced; a single loop non-changing algorithm, to minimize the computational complexity of SMA, and Ladybug tool is introduced as a solar load calculator (Parisi, 2013). Consequently, Rhino software, Grasshopper, Honeybee, Ladybug and simple python script components are collectively used for applying the algorithm to satisfy the goal of accessibility to architects.

#### *Methodology*

To reach an understanding of the overall simulation, a simplified methodology is first introduced; including the general steps and needed input. First, a two form states design for the building envelope SMA panels are introduced as basic geometries, i.e. initial form (input) and final form (geometrically optimized). Second, the SMA form is analyzed in terms of its temperature using direct and indirect solar heat loads as an input (air temperature and solar radiation). Third, the input of  $A_s$ ,  $A_f$ ,  $M_s$  and  $M_f$  temperatures is introduced to indicate the percentage at which the initial form is to change towards the final form. Fourth, the panels generated are arrayed upon a south façade (input) and the total heat loads (output) upon such facades are calculated over January and March (input). Finally, a comparison between the case of using SMAs to shift between two forms and the cases of using each of the two forms as a fixed geometry over the year is applied, which is based on the total solar loads on the south façade for each case in January and March; i.e. a comparison between three cases is applied.

#### *Limitations*

Based on the methodology introduced, the following set of limitations are taken into consideration to minimize complexity without compensating accuracy greatly:

- Change in SMA shape is applied in two dimensions only (only the cross section of the material in one direction is changeable)
- Shape output is simulated over 24 hours per day to reach more accurate results for any hour of that day
- Microscopic material change is disregarded (only macroscopic geometrical changes visible to the designer are considered)
- Two way SMA materials only are used such as Nickel Titanium
- Nickel Titanium Zirconium aged at a temperature of 550 °C for 48 hours is used for this specific simulation;  $A_s=60$  °C,  $A_f=100$  °C,  $M_s=40$  °C,  $M_f=20$  °C (Evirgen *et al.*, 2016)
- The solar heat loads simulation is applied upon a 3 meters width and 3 meters height southern facing façade
- The arrayed panels are all geometrically similar to each other
- The two fixed panels arrayed cases introduced are geometrically exactly similar to the resulting geometries from the SMA panel simulation; i.e. a fixed



panel having the SMA's March 1<sup>st</sup> 13:00 geometry and another having the SMA's January 1<sup>st</sup> 13:00 geometry

### Algorithm implementation

#### Geometrical Initial and Final States Optimization

The basic design is applied by using a modular panel to be arrayed along an elevation. By taking into consideration the limitations; the geometrical form is introduced as a flat NiTi square plane having a side length of 50 centimeters and thickness of 0.25 centimeter. Such plane is generated by extruding a NURBS (Non-Uniform Rational Basis Spline) curve in the form of a straight line along a straight path. In order to reach two states which can physically transform to each other, the NURBS line is modified using 5 control points where a curved plane is reached as shown in Figure 3. It is then optimized using Galapagos tool genetic algorithm to ensure the initial and final lengths of the NURBS curves are equal (Gamal, 2016). Finally, the initial state is morphed into the final state using a morph box that can be scaled gradually using a scale factor from 0 to 1; where 0 results in the *initial state* and 1 results in the *final state* as shown in Figure 3 and shown in the Grasshopper algorithm in Figure 4.

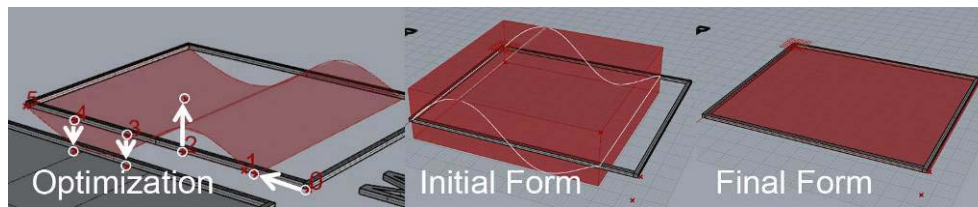


Figure 3, From Left to Right, Physical Optimization of Panel, Morphing Box Initial Form, Morphing Box Final Form

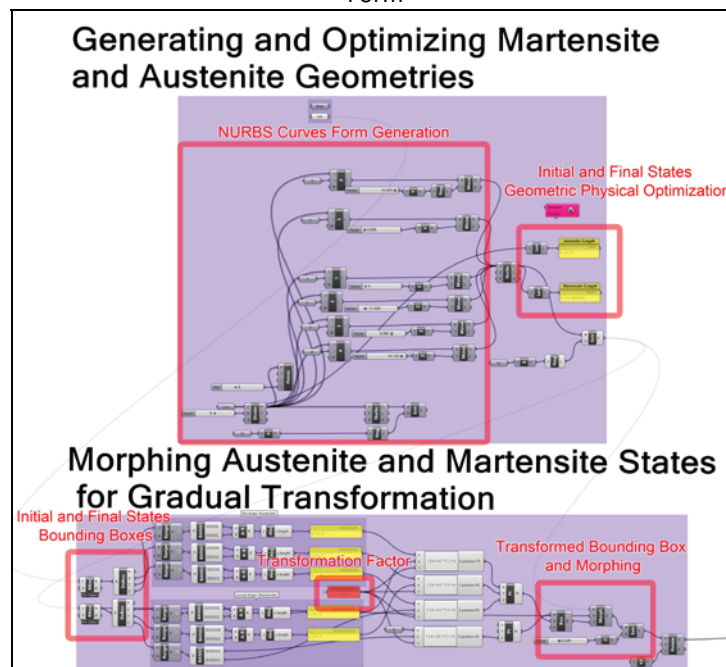


Figure 4, Grasshopper Panel Geometry Generator Algorithm

#### Material Temperature Calculation

After reaching the initial and final forms shown in Figure 3, the flat form is used as a base geometry for calculating the material temperature. To reach such calculation, the direct solar heat gain, indirect solar heat gain, surrounding air temperature and the material heat

transfer properties should be taken into consideration. For the surrounding air temperature, the material is assumed to have a temperature equal to the *dry bulb temperature* at the introduced date and hour. On the other hand for the *solar heat gain*, the following equation is introduced:

$$E = \rho \cdot v \cdot c \cdot \Delta T$$

Where  $E$  is the heat energy gain in joules,  $\rho$  is the density of NiTiZr in  $\text{gm/cm}^3$  (for Ni50Ti50 =  $6.45 \text{ gm/cm}^3$ ),  $v$  is the volume of the plane in  $\text{cm}^3$  (for the introduced panel =  $625 \text{ cm}^3$ ),  $c$  is the specific heat capacity of NiTiZr in  $\text{J/gm}^\circ\text{C}$  (for NiTi =  $0.32 \text{ J/gm}^\circ\text{C}$ ) and  $\Delta T$  is the change in the NiTiZr alloy temperature (Duerig and Pelton, 1994).

The previous equation has  $\Delta T$  and  $E$  as unknowns. For  $E$ , The following equation is used for calculation:

$$E = E'' \cdot f \cdot a$$

Where  $E''$  is the *total solar radiation* simulated in Kwh,  $f$  is a factor for transferring the energy into joules ( $f=3,600,000$ ),  $a$  is a factor to account for the NiTiZr absorptivity and color ( $a=0.15$ ; however, further experimental tests upon physical prototypes are needed for accuracy)

Using the calculated  $E$ ,  $\Delta T$  is computed and added to the initial material temperature (*dry bulb temperature*) as shown in Figure 5. However,  $E$  is always calculated based on the flat panel form to avoid nesting and infinite loops in the simulation. Thus, an *error margin* occurs because the change in the panel's form leads to a change in the  $E$  value. This problem can be solved using a different timer based simulation approach; i.e. higher computational complexity. This error margin is calculated as follows:

$$e = |(E1 - E2) / E2| \cdot 100$$

Where  $e$  is the error margin in %,  $E1$  is the total solar radiation of the flat plane in Kwh,  $E2$  is the total solar radiation of the transformed plane in Kwh.

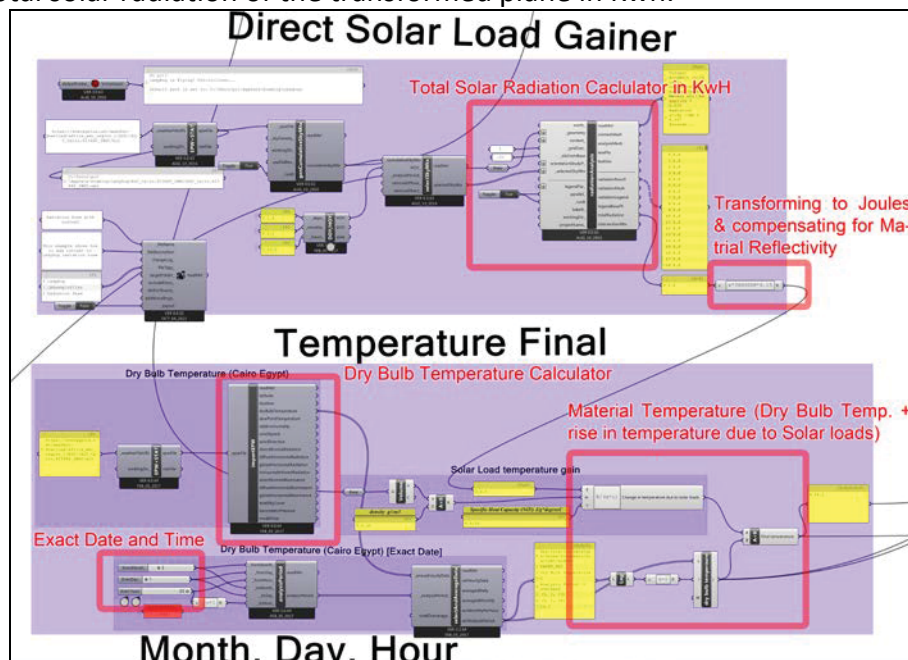


Figure 5, Grasshopper Material Temperature Calculator Algorithm

### Transformational Scale Calculation

For the final part of the SMA form change simulation, as stated previously, a scale factor is needed between 0 and 1 to indicate the geometrical morphing degree. The basic idea is to use the austenite and martensite temperatures where the following equations are used:

$$t=(T-A_s)/(A_f-A_s).....(1)$$

$$t=(T-M_f)/(M_s-M_f).....(2)$$

Where  $t$  is the *transformational factor*,  $T$  is the material temperature; all temperatures are measured in °C

Such value is calculated differently according to the heat transfer state of the material; i.e. the material is being heated or cooled. To indicate such value, for every simulation date, the total radiation of such date ( $E$ ) and an hour later ( $E'$ ) are used to calculate two temperatures ( $T_2$  corresponds to  $E'$  and  $T_1$  corresponds to  $E$ ); then  $T_2$  is subtracted from  $T_1$  as shown in Figure 6. If  $T_2-T_1$  value is negative, the material is cooling down; equation 1 is used. On the other hand, if positive, the material is heating up; equation 2 is used. It is important to note that a python script component is used to keep the highest  $t$  value that the simulation reaches over a day during heating; since when cooling, such value should be kept constant until a lower transformation value is reached (the material keeps its final transformation state after heating until the martensite temperature is reached).

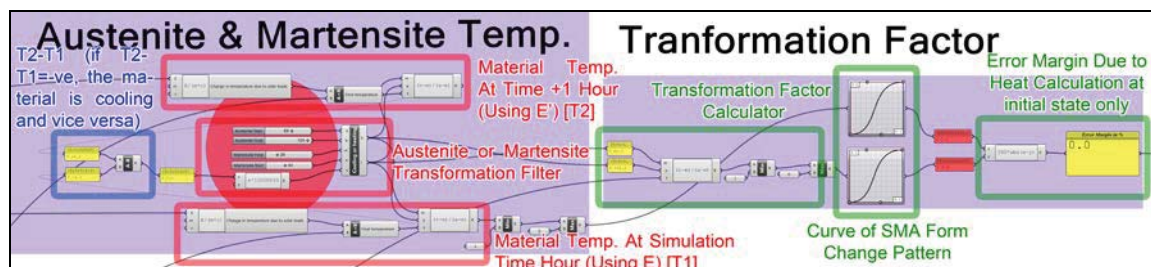


Figure 6, Grasshopper Transformation Factor and Error Margin Calculator

#### South Elevation Panel Array and Solar Heat Gain Calculator

After simulating the geometries for the SMA panel at different dates, two dates are chosen to explore the effect of using a skin of arrayed SMA panels at each date. January 1<sup>st</sup> at 13:00 is chosen as a cold day sample where the SMA panel is unsealed as shown in Figure 7 and March 1<sup>st</sup> at 13:00 is chosen as a warm day sample where the SMA Panel is sealed as shown in Figure 7 as well. Furthermore, each state; the sealed state and the unsealed state, is assumed to be used over the façade as a fixed skin. Thus three cases are present; 1) SMA case having sealed state in March and unsealed state in January, 2) Sealed fixed state over the whole year and 3) Unsealed fixed state over the whole year as well.

Using Grasshopper, the sealed and unsealed panels are arrayed over a 3 meters width and 3 meters height southern building façade. The south elevation is subdivided into 50 cm side length squares and the panels are oriented upon each subdivision to reach the arrayed resultant. For the heat loads, Ladybug solar analysis component is used. The input includes 1) the arrayed geometry as a barrier input according to the case to be calculated, 2) the south elevation as calculation plane input, 3) Cairo, Egypt weather file as an input location, and 4) Hour of year as a date input which is calculated using a separate component (input month, day and hour); such inputs are shown in the algorithm in Figure 8. This process produces two total solar heat load results; January and March, for each one of the three cases. In other words, six values are reached from such simulation algorithm.

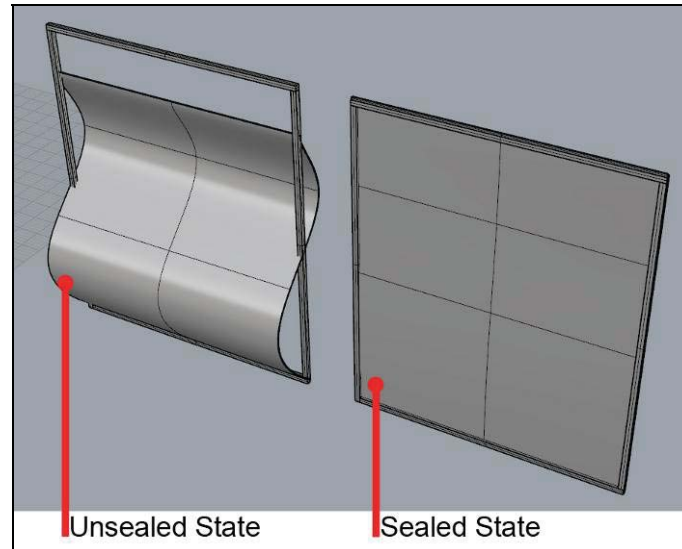


Figure 7, SMA Two Resultant Forms for January 1<sup>st</sup> 13:00 (Unsealed) and for March 1<sup>st</sup> at 13:00 (Sealed)

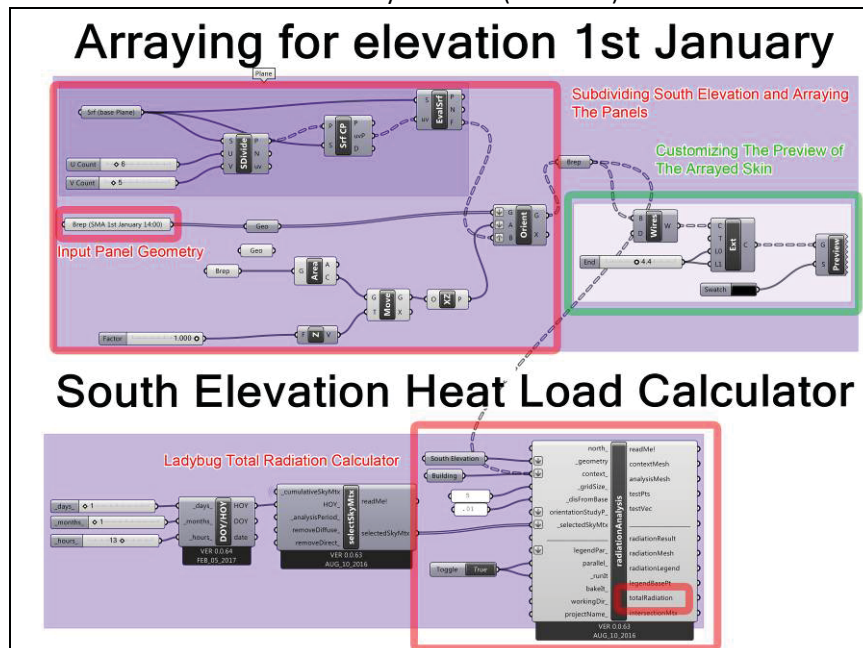


Figure 8, Algorithm for Solar Load Calculation Upon a 3m\*3m Southern Building Façade to be implemented for the three cases in January and March for each

## Results

For clarity, the results are broken down into two parts; 1) the SMA form change simulation results and 2) the solar heat loads calculations results. Each simulation range of resultants are explored and analysed. However, for the solar heat loads calculation a limited amount of output is reached for feasibility of comparison.

### SMA Form Change Simulation Results

For the SMA simulation, the product is a collected algorithm as shown in the previous figures that can show the *degree of transformation* a SMA undergoes by introducing the location, time, austenite and martensite temperatures, SMA specific heat, SMA density and the panel's initial and final form. Samples of results for the *material temperature*, the *transformational factor* and the *error margin* are shown in Table 1. Also visualized resultants



are shown in Figure 9 for clarifying the transformational process in March 1<sup>st</sup>, and full day visualizations are shown in Figure 10 for March 1<sup>st</sup> and Figure 11 for August 1<sup>st</sup>.

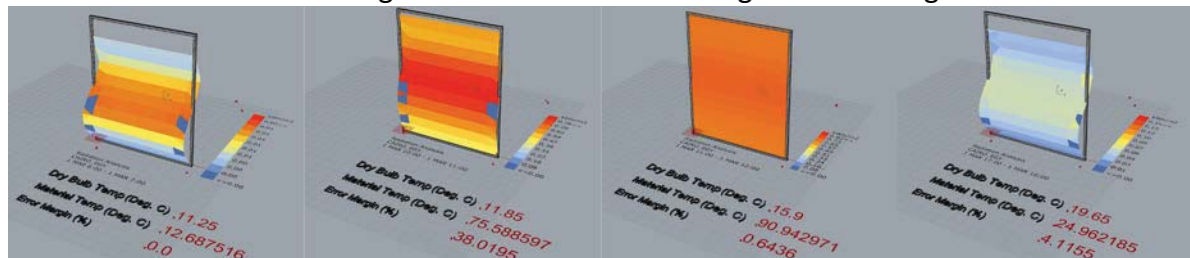
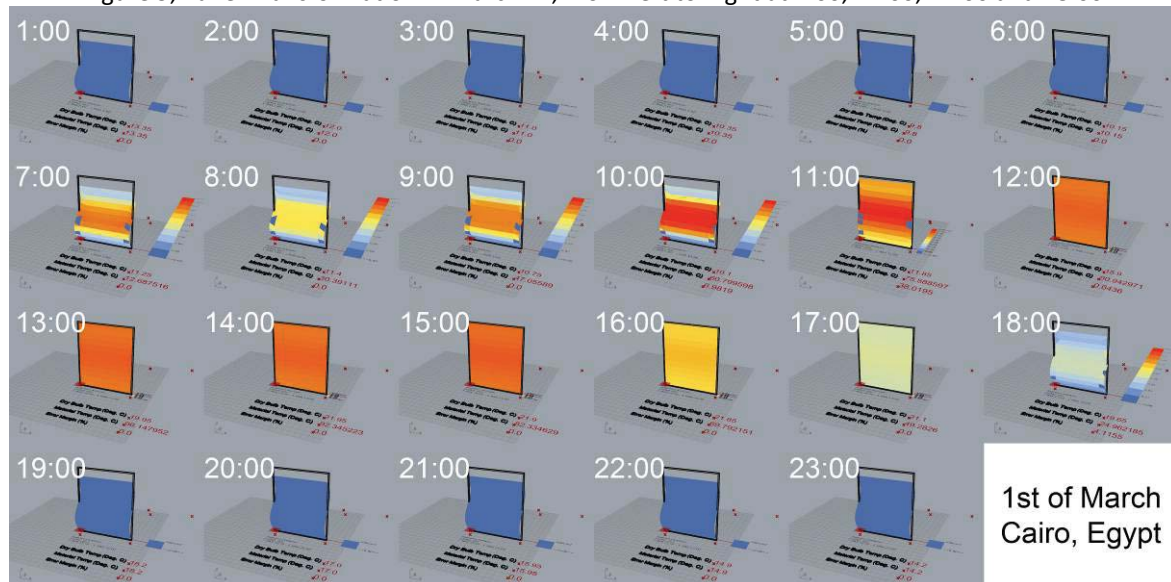
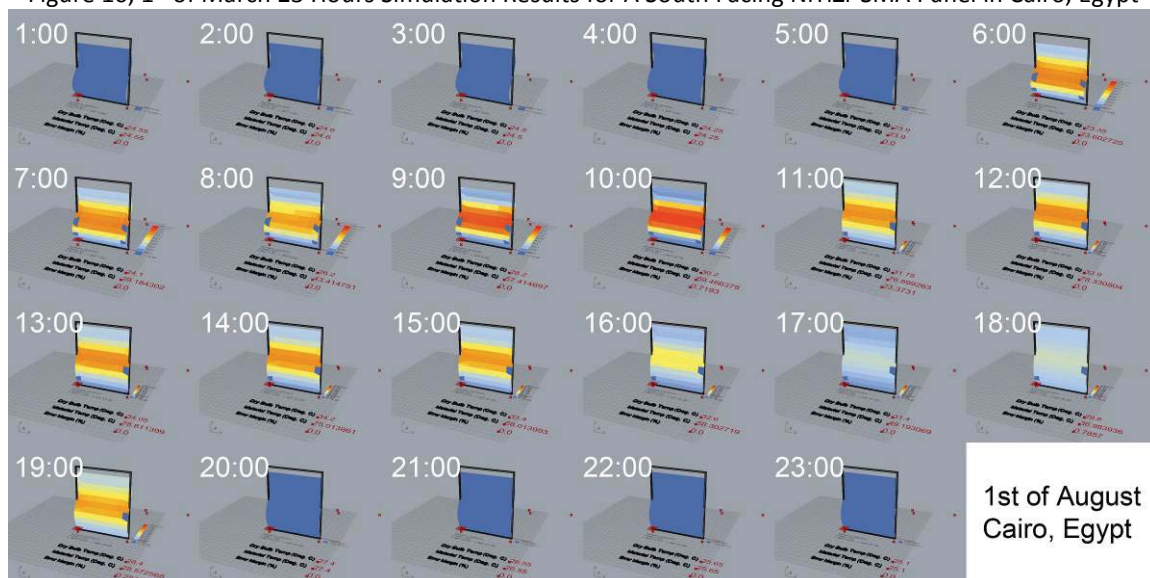


Figure 9, Panel Transformation in March 1<sup>st</sup>, From Left to Right at 7:00, 11:00, 12:00 and 18:00



1st of March  
Cairo, Egypt

Figure 10, 1<sup>st</sup> of March 23 Hours Simulation Results for A South Facing NiTiZr SMA Panel in Cairo, Egypt



1st of August  
Cairo, Egypt

Figure 11, 1<sup>st</sup> of August 23 Hours Simulation Results for A South Facing NiTiZr SMA Panel in Cairo, Egypt



Table 1, Simulation Results for 1<sup>st</sup> of January, March and August for 23 hours Showing the Transformation Factor, Material Temperature and Error Factor

Time of the Day	1st January			1st March			1st August		
	Transformation factor	Material Temperature (°C)	Error Factor (%)	Transformation factor	Material Temperature (°C)	Error Factor (%)	Transformation factor	Material Temperature (°C)	Error Factor (%)
1:00	0	11.4	0	0	13.35	0	0	26.75	0
2:00	0	11	0	0	12	0	0	24.55	0
3:00	0	10.6	0	0	11	0	0	24.2	0
4:00	0	10.2	0	0	10.35	0	0	23.8	0
5:00	0	9.8	0	0	9.8	0	0	23.35	0
6:00	0	9.3	0	0	10.15	0	0	22.9	0
7:00	0	9.6	0	0	12.688	0	0	24.46	0
8:00	0	17.624	0	0	30.391	0	0	37.995	0
9:00	0	32.698	0	0	47.056	0	0	49.513	0
10:00	0	43.062	0	0.07	60.8	7	0	58.224	0
11:00	0	49.353	0	0.684	75.589	38	0.044852	68.295	5.7
12:00	0	54.686	0	0.958	90.943	0.6	0.064402	74.163	18
13:00	0	55.227	0	0.958	96.148	0	0.064402	77.129	0
14:00	0	50.046	0	0.958	92.345	0	0.064402	78.433	0
15:00	0	42.976	0	0.958	82.335	0	0.064402	76.804	0
16:00	0	33.582	0	0.958	69.792	0	0.064402	72.58	0
17:00	0	17.833	0	0.958	49.283	0	0.064402	65.912	0
18:00	0	14.5	0	0.129	24.962	4.1	0.064402	59.366	0
19:00	0	14.2	0	0.129	18.2	0	0.064402	48.148	0
20:00	0	14.2	0	0.129	17	0	0.064402	33.32	0
21:00	0	14	0	0.129	15.95	0	0.064402	30.65	0
22:00	0	13.6	0	0.129	14.9	0	0.064402	29.55	0
23:00	0	12.6	0	0.129	14.2	0	0.064402	28.25	0

By analysing the results it can be viewed that the SMA transformation starts when the material temperature reaches the  $A_s$  (60°C) during heating and the  $M_s$  (40°C) during cooling where: 1) low temperature months show no change in the *transformation factor*, 2) warmer months show high *transformation factors* which may not rebound to zero due to the high temperatures 3) the *error factor* reaches up to 38% at the first transformation step of each day, which can be minimized to reach 0% in all cases by using a timer based grasshopper script to calculate the heat load of the plane at its transformed state rather than its sealed state.

### Solar Heat Loads Calculations Results

The second part of the simulation product is an algorithm calculating the solar heat loads upon a southern façade having an extra arrayed skin of any selected geometry. As for the numerical results from the simulation; the solar heat loads values upon the 3m\*3m

southern building envelope are clearly introduced in Table 2. Each case is numbered, as previously introduced, with two values of solar heat loads in Kwh calculated for each. Furthermore, visualized images for the simulation cases are introduced for each state in Figure 12 with the total radiation (total solar heat loads) shown in the figure.

Table 2, Total Heat Loads Upon a Southern (3m\*3m) Building Façade Having Arrayed Panels as An Extra Skin For Shading (Unsealed and Sealed Refer to the Geometric States of the Previously Simulated SMA Panel)

Case 1: SMA Arrayed Skin			Case 2: Fixed Skin Optimized for Minimizing Heat Loads in March		Case 3: Fixed Skin Optimized for Allowing heat loads in January	
Date	State	South Elevation Total Heat Loads (KWh)	State	South Elevation Total Heat Loads (KWh)	State	South Elevation Total Heat Loads (KWh)
1 <sup>st</sup> Jan 13:00	Unsealed	0.363919	Sealed	0.074458	Unsealed	0.074458
1 <sup>st</sup> March 13:00	Sealed	0.034102	Sealed	0.034102	Unsealed	0.53545

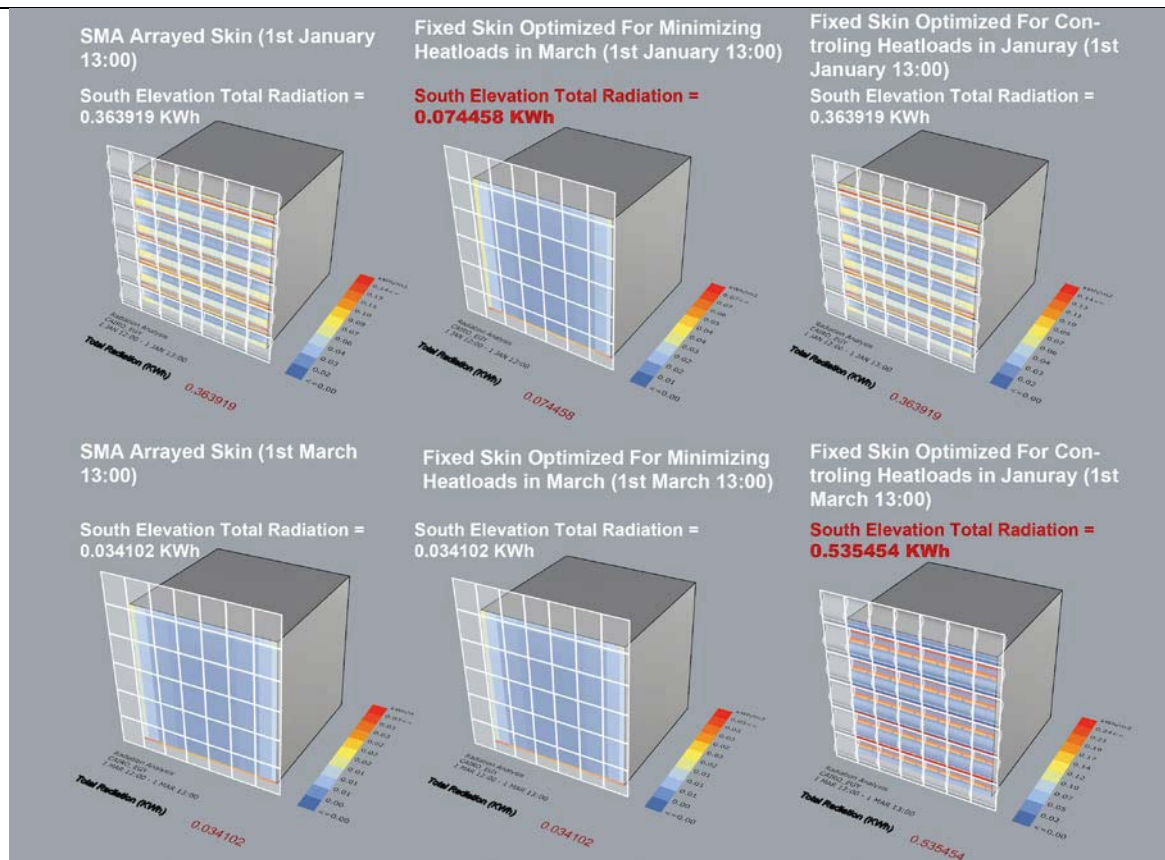


Figure 12, Sothern Elevation Total Thermal Heat Loads Simulations Arranged Similar to Table 2 where Non-Optimized States Are Highlighted in Red

A brief analysis of the results clearly shows the advantage of using SMAs to change form and adapt to heat changes. This is clearly visible when noting that SMA envelope

reaches the needed results in both dates; high thermal loads in colder days (0.36 Kwh in January) and low thermal loads in warm days (0.034 Kwh in March). In comparison the other 2 cases show various inconsistencies; 1) the fixed sealed skin results in minimizing solar heat loads in colder days (0.074 KWh in January) and 2) the fixed unsealed skin results in maximizing solar heat loads in warmer days (0.54 KWh in March). Such inconsistencies mean that the SMA case lets in 67% more solar loads in January in relation to the fixed sealed case, at the same time, it means that the SMA case seals off 89% more solar loads in March in comparison to the fixed unsealed case. Optimizing such values to decrease the inconsistencies is applicable by switching to a louver design including fixed vertical and horizontal sun-breaker design.

### **Enhanced SMA Building Envelope Design Approach**

As previously stated, the design of a CABS using shape memory alloys shows a direct change in solar heat energy into a change in form; no electricity involved. However, it is crucial to state that hurdles are present in the previously mentioned implementation of SMAs. First, SMAs manufacturing process is extremely hard to be maintained over large panels such as the 50cm length and 50 cm width panel introduced in the simulation; minimizing dimensions leads to simplifying the manufacturing and shape memory implementation process. This is mainly because non-conventional manufacturing methods, where physical cutting tools do not reach the NiTi alloy, are very common in smaller dimensions; which minimizes the cutting materials loss (Davem, 2016). Furthermore, conventional manufacturing methods, where cutting and drilling materials are used, lead to high temperatures which may lead to changes in the subsurface of the NiTi panel (Manjaiah, Narendranath and Basavarajappa, 2014). Second, even if manufactured, the shape change control needs further experimentation to take into account different forces such as buckling. From this standpoint, and by going back to Figure 2, it is clearly more logical to minimize the usage of SMAs to reach a similar resultant. In other words, the shape memory alloys can be diminished into a spring or a rod that changes its form to control another material that the whole panel is made of; can be a synthetic fabric for example. In that case the whole point would be to design an exposed SMA that can change the form of a panel; made of flexible material, to reach results as simulated above. i.e. an exposed SMA actuator that controls the envelope due to direct solar loads as a CABS design.

### **Conclusion**

The introduced methodology and algorithm devises a very simplified approach for simulating dynamic building envelopes or CABS at an age where most modelling techniques are devised towards static building envelopes. Furthermore, the introduced approach focuses upon using SMAs as a form changing building envelope due to temperature change. On one hand, over the sustainable scale, this approach deprives the form changing envelopes from the need of electric energy which deems the form change as a zero electricity one; i.e. it is totally dependent on renewable energy. Also the approach highlights the efficiency of form changing building envelopes in relation to fixed ones in terms of controlling solar loads. In other words, it theoretically proves the presence of energy savings using the zero electricity SMA envelopes.

On the other hand, over the design and material choice scale, this approach opens up the potential of devising the same morphing technique during the simulation to be triggered using different energy stimuli; i.e. shape change of a material due to a change in humidity,

pressure, optical light...etc. Such potential will give architects an experimental tool for new materials, where the designer can explore the potential of such new materials upon the building envelope. This can greatly influence the designers' material choices; which in turn can facilitate the introduction materials that may not have been implemented directly upon building facades beforehand opening up further potential of finding more energy efficient and adaptive envelope designs. However, it is important to note that the introduced algorithm needs further refinement concerning the accuracy of calculations. This refinement can be achieved by introducing a highly accurate database for different shape changing materials' properties; which when implemented will unlock the architects' full potential of creative material choices during the design phase with the awareness of their effect upon energy consumption in general.

## References

- Burton, D. S., Gao, X. and Brinson, L. C. (2006) 'Finite element simulation of a self-healing shape memory alloy composite', *Mechanics of Materials*, 38(5–6), pp. 525–537. doi: 10.1016/j.mechmat.2005.05.021.
- Davem, J. P. (2016) *Materials Forming and Machining Research and Development*. Woodhead Publishing.
- Duerig, T. W. and Pelton, A. R. (1994) 'Ti-Ni shape memory alloys', *Materials properties handbook: Titanium alloys*, 683, pp. 1035–1048.
- Evirgen, A., Karaman, I., Pons, J., Santamarta, R. and Noebe, R. D. (2016) 'Role of nano-precipitation on the microstructure and shape memory characteristics of a new Ni<sub>50.3</sub>Ti<sub>34.7</sub>Zr<sub>15</sub> shape memory alloy', *Materials Science and Engineering A*. Elsevier, 655, pp. 193–203. doi: 10.1016/j.msea.2015.12.076.
- Gamal, Y. (2016) 'Form and Nano Smart Building Envelopes Post 20th Century', *Master Thesis in Cairo University, Faculty of Engineering, Architecture Department*.
- Gao, X., Huang, M. S. and Brinson, L. C. (2000) 'A multivariant micromechanical model for SMAs Part 1. Crystallographic issues for single crystal model', *International Journal of Plasticity*, 16(10–11), pp. 1345–1369.
- Harris, M. W. and J. (2002) *Intelligent Skins*, Elsevier. Available at: <http://medcontent.metapress.com/index/A65RM03P4874243N.pdf>.
- Juhasz, L., Schnack, E., Hesebeck, O. and Andra, H. (2002) 'Macroscopic modeling of shape memory alloys under nonproportional thermo-mechanical loadings', *Journal of Intelligent Material Systems and Structures*, 13(12), pp. 825–836.
- Lazarovich, N., Capeluto, G. and Silverstein, M. S. (2015) 'Smart material systems for high performance building envelopes', in *Adaptive facade network – Europe*. COST, p. 70.
- Loonen, R. C. G. M., Trčka, M., Cóstola, D. and Hensen, J. L. M. (2013) 'Climate adaptive building shells: State-of-the-art and future challenges', *Renewable and Sustainable Energy Reviews*, 25, pp. 483–493. doi: 10.1016/j.rser.2013.04.016.
- Manjaiah, M., Narendranath, S. and Basavarajappa, S. (2014) 'Review on non-conventional machining of shape memory alloys', *Transactions of Nonferrous Metals Society of China (English Edition)*. The Nonferrous Metals Society of China, 24(1), pp. 12–21. doi: 10.1016/S1003-6326(14)63022-3.
- Parisi, L. (2013) *Contagious Architecture Computation, Aesthetics, And Space*. London: MIT.
- Patoor, E., Eberhardt, A. and Berveiller, M. (1988) 'Thermomechanical behavior of shape memory alloys', *Archives of Mechanics (Warszawa)*, 40, pp. 775–794.
- Patoor, E., Eberhardt, A. and Berveiller, M. (1994) 'Micromechanical Modelling of the Shape Memory Behavior', in *ASME International Congress and Exposition*.
- Patoor, E., Entemeyer, D., Eberhardt, A. and Berveiller, M. (2000) 'Stress-induced martensitic transformation in polycrystalline alloys', *Zeitschrift für Angewandte Mathematik und Mechanik*, pp. 443–444.
- Tanaka, K., Kobayashi, S. and Sato, Y. (1986) 'Thermomechanics of transformation pseudoelasticity and shape memory effect in alloys', *International Journal of Plasticity*, 2, pp. 59–72.

# Revealing the Sustainable Design Properties of a Vernacular House in Alaçatı, Turkey by Building Energy Modelling

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**Abstract:** Alaçatı is a densely visited unique Aegean town on the west coast of İzmir, Turkey. It has been famous after 1990, because of its authentic streets with Greek architecture, nature and culture. Since the most important pull factor of Alaçatı is to be the vernacular houses, the historical vernacular houses were converted into hotels for the accommodation and cultural experience demand of the tourists. The present study deals with the hotel that is number 68 of the 1005<sup>th</sup> street, which is converted from a 150 year old Greek house in Tokoğlu province of the historical centre of Alaçatı. The purpose of the study is to reveal the sustainable design properties that the house contains by both conceptual and quantitative aspect. Regarding to this aim, the house has been modelled by a digital energy modelling program. The architectural drawings, climate and weather data from Adnan Menderes Weather Station, materials and building usage data, and the restoration and survey works of the house have been used as the needed information for the energy model of the house. The sustainable design properties were presented on the model for the winter and summer condition respectively, as the percentage effect on the heating and cooling energy need for the hotel. As the result, it is observed that some of the passive design properties reduce the heating and cooling energy, some of them don't have any effect and some of them are recorded to be far from being sustainable as they increase the energy need of the building. It is anticipated that the elicited results from the study are to be a guide for new buildings that are going to be designed in the area in terms of sustainable architecture.

**Keywords:** Sustainable design, Alaçatı, building energy modelling, vernacular architecture

## Introduction

Alaçatı is a tourism centre in İzmir, Turkey, which is renowned with its cultural and natural values, authentic streets and vernacular architecture. The town is densely visited by tourists during the spring and summer seasons. Regarding to the tourism appeality of the town the demand for accommodation facilities grows day by day. Since the vernacular architecture of Alaçatı is the major pull factor, the historical houses are converted into hotels and new hotels following the vernacular architecture principles are built to cope with the accommodation demand.

The growing number of hotels lead to increase in energy consumption in Alaçatı. The vernacular houses of Alaçatı contain sustainable design futures that conform to the climate of the town, which are based on an accumulated knowledge of experience. Concerning to that, the present study aims to evaluate the sustainable design attributes that the vernacular houses of Alaçatı contain to be a guide for new building designs. In order to evaluate these futures, a vernacular house which was converted into a boutique hotel is chosen as a case building for inspection.

There are several studies that employ qualitative approach for evaluating the sustainable design properties of buildings. Kahn practiced a vernacular courtyard house constructed in 1898 in Pakistan in terms of sustainable architecture. The research employs a conceptual approach, which is based on the thermal performance of the courtyard respecting to day lighting and solar shading at the same time. The sustainability properties that the research evaluates are to be roof overhangs, operable shading devices, fabric fans



for airflow, effect of water fountain, building form, window to wall proportion and glare control elements (Kahn, 2010). A research on the environmental considerations of Malay vernacular houses was conducted by GhaffarianHoseini et al. Through a qualitative perspective the study evaluates the sustainability futures that the Malay houses contain to prepare guide of sustainable design for new houses in the area. In the article the climatic considerations were presented as adequate ventilation, reducing humidity, increasing air passage for cooling, controlling direct solar radiation, protection against rain, orientation, minimizing the heat transmission, indirect source of light for minimizing heat gain and adequate natural plantation in the surroundings (GhaffarianHoseini et al, 2014). The sustainable architecture properties of different types of Portuguese vernacular houses were presented by Fernandes and Mateus. Regarding to conforming to the climate of the region, several methods are employed in the traditional houses in Portugal, thus with the knowledge of experience these houses obtain energy efficiency. These properties, which were presented to be a guide for new buildings, are the choice of the construction site and organization of the placement of the houses in the villages, promotion of natural ventilation, reducing the solar gains in summer, capturing solar gains in winter, reducing heat transfer through the building components and provide efficient management of sources (Fernandes and Mateus, 2012).

There are also several studies that use quantitative approach to evaluate the sustainable design properties of buildings in the literature. A historical building in Portugal was assessed in terms of the effect of natural ventilation on the energy sustainability by Salehi et al. The evaluation method is based on energy consumption results of the energy model of the building with the original case and other ventilation techniques applied (Salehi et al, 2017). Wang et al conducted a study on seeking better passive energy saving techniques for houses in the climate of Cardiff. The study is based on an energy model, on which several passive design strategies, such as orientation, window to wall ratio, direct gain systems were applied and compared with the base energy consumption results of the building (Wang et al, 2009). Okba investigated the effect of building envelope on the annual energy demand of the buildings in Red Sea Coast of Egypt. An energy modelling program is used in the study to calculate and compare the energy demands of the different building envelope and form designs. The study provides information for the new buildings to be designed in the climate of the Red Sea Region (Okba, 2005).

In contrast with the mentioned studies above the present paper assumes a mixed approach that contains an empiric and a conceptual method. The case building is modelled by a building energy demand estimation program and evaluated by several sustainable design criteria, which are determined from the literature review.

### ***Case Building: Hotel Number 68 of the 1005th Street, Alaçatı***

The case building is one of the Alaçatı vernacular houses from 19<sup>th</sup>, which lies in the 1005<sup>th</sup> Street of the historical centre of the town. It was converted into a boutique hotel between the years 2005-2007 by the Architect Salih Seymen (Seymen, 2010). It has two floors and 5 guestrooms. The main entrance is from the north side of the house inside the front private garden. The building has two bay windows, which are the most significant properties of the vernacular houses of Alaçatı (Figure 1).



Figure 1. After the conversion, hotel number 68 of the 1005th Street, Alaçatı (Archive, 2017).

## Methodology

As the study aims to reveal the sustainable design properties of the case building by a qualitative and quantitative aspect, a checklist of evaluation criteria was determined by the literature review on the previous studies of sustainable design scholars (Banani et al, 2016; Jankovic, 2017; Busato, 2003; Sadineni et al, 2011; Terim, 2011; Olgyay, 1963). The criteria that checklist contains were examined in two different approach as conceptual and quantitative properties. The conceptual evaluation corresponds to the climate responsivity strategies in the literature, while the quantitative evaluation does to interpretation of the results from the building energy model of the hotel (Figure 2).

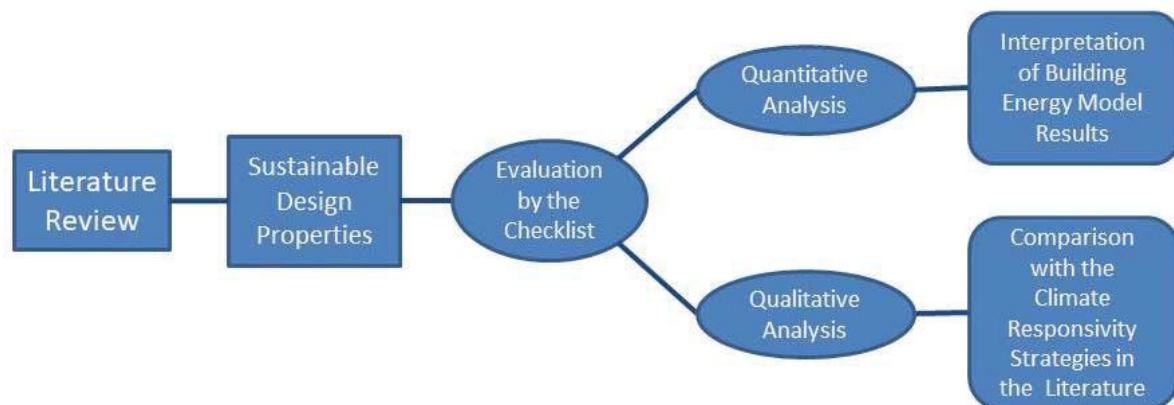


Figure 2. Flow diagram of the evaluation methodology (Archive, 2017).

The needed information for the building energy model was elicited from Adnan Menderes Weather Station, materials and building usage data, and the restoration drawings. The criteria of sustainable architecture were determined to be building form, sun exposure and shading strategy, natural ventilation, effect of neighbourhood and adjacency, building materials, roof style, orientation, integration of greenery and interior space organisation.

### ***Weather Data of Alaçatı, İzmir***

According to Köppen Climate Classification Alaçatı is under the 'Csa' section, which refers to hot and temperate (Rübel and Kottek, 2010). The average air temperature is 15°C – 38°C in summer days, while in the winter days it changes between -2°C – 16°C. The average heat by the incident sun varies between hourly 650 W.h/m<sup>2</sup> and 110 W.h/m<sup>2</sup> in a day. For all year mean relative humidity in a month is %50, while in the winter days it is %70. Average wind speed is 5m/sec and the prevailing wind direction is north-west. It annually blows 300 days in average. The consistent winds from the south and north direction together with the breezes from the Alaçatı Bay make possibilities for passive cooling by natural ventilation techniques (Terim, 2011; Energyplus.net , 2017).

### ***Energy Modelling of the Case Building***

The case building was modelled in the energy program that has Energy Plus groundwork, regarding to the plan, section and elevation drawings (Figure 3). The building user schedule data were set according to the information that was elicited from the owners. All the building materials were identified to the energy model. For cooling air conditioning units were located in the energy model, while natural gas heating units were located for heating. The temperature set points were determined as 20°C for heating and 26°C for cooling. Only the energy consumption values for cooling and heating in kilowatt-hour (kWh) during the whole year were taken into account in the present study.

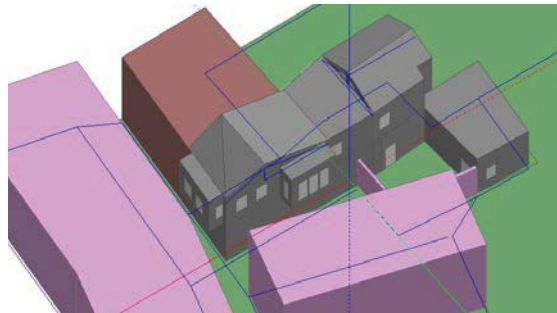


Figure 3. Building energy model of the case hotel (Archive, 2017).

The energy results of the case building's current condition model are taken as the control values. The model is modified according to the properties that are to be measured and the simulation is run as that way. The energy consumption value difference between the values of the control model and modified model denotes the influence of the specific criterion. Finally the proportion of the influence value in the control value is presented in percentage (Figure 4). This process is applied to each concerning sustainability criteria and interpreted.

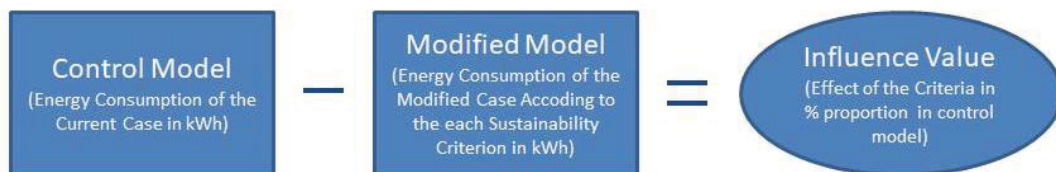


Figure 4. Quantitative evaluation method of the sustainability criteria (Archive, 2017).

### ***Revealing the Sustainable Design Properties of the Case Building***

The evaluation of the sustainable design properties of the case building is done in this section respectively under the subtitles.

#### ***Building form***

Building form is a major and initial factor that determines the main attitude of the building regarding to the outside environment (El Demetry, 2014). The form of the hotel is based on the union of two rectangular prisms, which are the major body aligned on the east-west axis with two floors and the single floored smaller part containing only one guest room. Together with the neighbour building in the north side of the hotel, the form of the building creates a surrounded open space in the entrance of the building as a garden for leisure usage of the users (Figure 5). The reason why the garden is blocked from three sides is not only to attain a definite private space for the users from the street, also creating a safer place against the continuous winds of Alaçatı in winter, and provide shading against the excessive heat of the direct sunlight in summer.

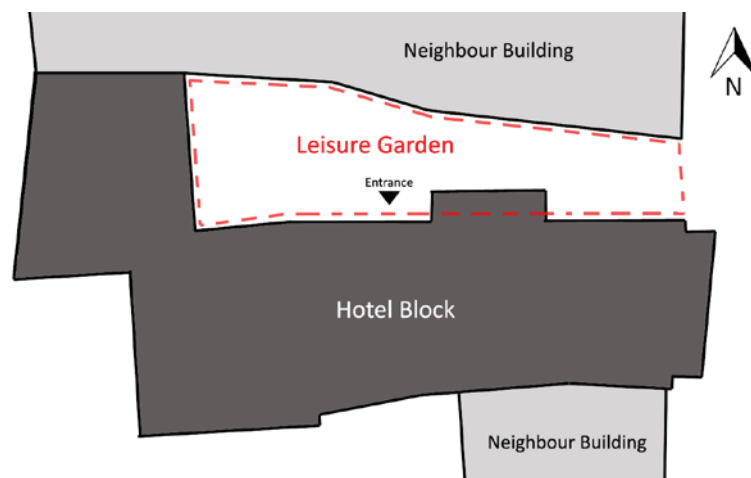


Figure 5. Surrounded open space for leisure usage (Archive, 2017).

The optimum building plan length and width ratios for each climatic zone are studied and presented by Olgyay, in terms of energy efficiency. The proper ratio for the hot and humid climate is noted to be between 1:1.7 and 1:3 (Olgyay, 1963). The plan ratio of the hotel is 1:3.6, which exceeds the optimum range.

At first glance to the building form, the bay windows on the street and garden side of the building take the attention as first floor extrusions. The bay window on the east side of the building is combined with the guest room, while the one on the north side is used as a separate closed balcony. The bay windows are widely used in the vernacular architecture of Alaçatı, and most of them have contribution for the building energy demand. It widens the building envelope and creates more surfaces for sun exposure for heat gain. In the correct application bay windows can act as a sun space to reduce the heating load in winter. Also in summer they can create shading for the ground floor spaces, while letting the sun inside in winter, when it is located in the south façade. In the present case the bay windows don't have any help to heating or cooling load, rather they raise the energy demand. According to the energy model of the hotel, the bay windows increase the energy demand of the building for heating and cooling by %3.1 in the whole year. It is detected that the bay windows don't have any effect on cooling load in summer with %0.2 decrease, while they increase energy



demand in winter critically by %5.3. The reason why the bay windows do not contribute passive heating or cooling and rather harming is the placement of them. The bay window on the north side of the building is under shadow during the whole year, and the one on the east side has incident direct sunlight only in summer mornings. Regarding to the insufficient sun exposure on the bay windows, they only increase the surface that loses heat in winter.

#### *Sun exposure and shading strategy*

Given that the major challenge of the climate of Alaçatı is the excessive heat in the summer, which is originated by the direct sun exposure, shading strategy for the buildings in the area deals major significance for adaptation to the climate. In the present study the neighbour buildings and the case hotel are located adjacent to each other from their north and south facades. Regarding to that, the street lies on the north-south axis with a thick boundary on the west and east sides by the buildings, protected from the sun longer during the summer season. This formation of buildings also leaves thinner façades to the street side and back gardens, which are protected from the sun by trees. The shading strategy and the position of the sun for 15th of June are shown in the Figure 6 respectively as the morning, noon and evening time.

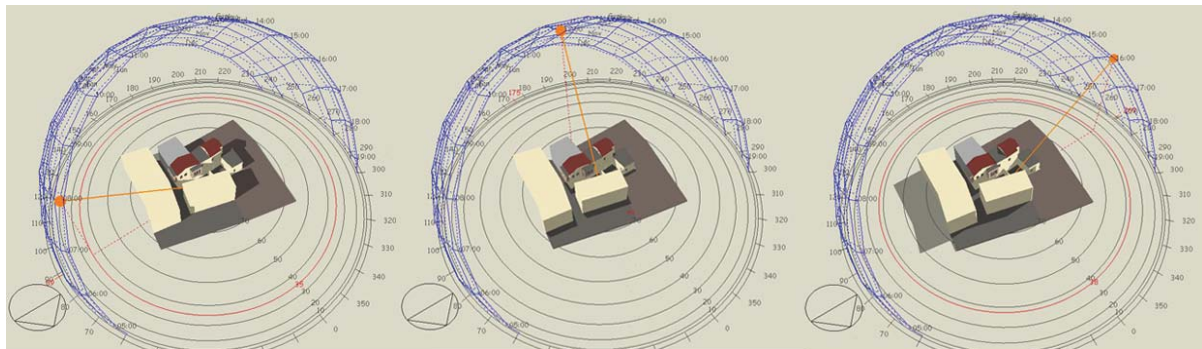


Figure 6. Position of the sun and shading strategy diagram for the case building, in the morning, noon and evening of the 15<sup>th</sup> of June (Archive, 2017).

The windows of the hotel building don't have any shading elements, mostly because of the direction of the openings. In the building energy model, fixed shading elements were added on the all windows in order to check the effect of the window shades on the cooling and heating load of the building. As it is seen in the Figure 6, the façades that have windows are protected from the sun almost all the day time. Regarding to that, it was expected from the shading elements that were added on the energy model to create prevention on only the ambient sunlight. According to the energy model the added shading elements decreased the cooling load in summer days by %3, and increased heating load in winter by %2. In the whole year it affects the total energy consumption for heating and cooling very slightly by %0.1. It is observed from the result that shading elements for the windows should be used only in summer with a controllable system, since in winter it prevents heat gain by the sun.

#### *Natural ventilation*

Natural ventilation deals great significance in the hot climates, like Alaçatı (Ibiyeye et al, 2016; Maatouk, 2007; Terim, 2011). Especially the continuous windy air of Alaçatı provides opportunities for passive cooling strategies by using natural ventilation.

To see the effect of natural ventilation in the case building, the annual energy consumption for heating and cooling was observed with and without natural ventilation.



The natural ventilation was set according to the minimum temperature control as 24°C, which means the windows are operated so long as the inside air temperature is not lower than 24°C. The difference between the natural ventilation on and off values shows the influence. According to this method the natural ventilation increases the heating load slightly by %0.3, decreases the cooling load effectively by %20, and decreases total annual energy consumption by %7.6.

#### *Effect of neighbourhood and adjacency*

It was mentioned before that the case hotel is inside a thick tissue of adjacent building neighbourhood. It has an adjacent block in the south, and very close neighbour buildings in the east and north. Only the west side of the building has a garden with thick greenery and trees. While the close neighbour buildings create shading for the building, the adjacent neighbour acts as a thermal boundary between the inside and exterior environment, that helps slowing the heat transfer. According to the energy model the effect of adjacency and the neighbourhood has a slight decrease on heating load by %0.8 and a major decrease on the cooling load by %8.3 in hot season. It decreases total annual energy usage by %3.7.

#### *Building materials*

The materials of the building were preserved and restored according to the original, which are 60 cm thick Alaçatı tuff stone load bearing walls and wood frame system in the bay windows. These materials are widely used in the vernacular houses of Alaçatı and they belong to knowledge of experience by years. In order to explore their influence on the heating and cooling load, the data elicited from the energy model with original materials were compared with the energy model with typical exterior wall that is used in the new buildings of the Alaçatı, which has 19cm thick aerated brick, 2cm extruded polystyrene (XPS) insulation board, plaster and paint in the both sides (Figure 7).

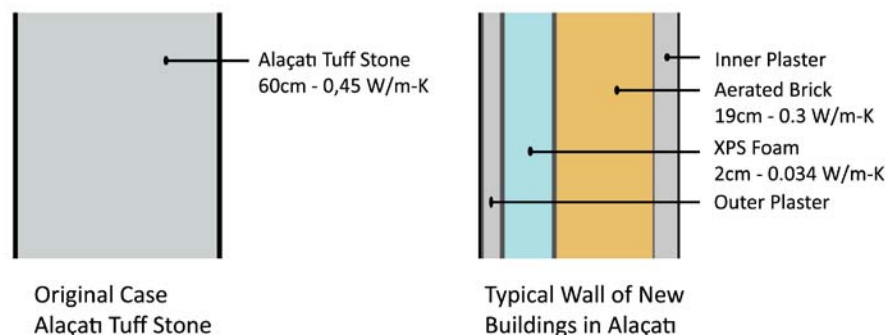


Figure 7. Comparison by section scheme between the original wall material and the typical new building walls of the area (Archive, 2017).

Result showed that the local Alaçatı tuff stone bearing wall and wooden frame bay windows increase the heating load by %2.6, decrease the cooling load slightly by %1.1, and increase the total annual energy consumption by %1.2. The reason why the vernacular materials do not contribute the energy saving is their porous body, which lets the exterior air through, so as the outside heat. In contrast with the widely known phenomenon of the sustainable effect of the vernacular materials, in the current case they don't help for the passive energy saving.

#### *Roof style*

The building has two separate gable roofs on the major block, on top of two guest rooms, made of wooden structure, covered with pantile cover in the outside and wooden ceiling

cover inside. In comparison with the general flat roof application with thermal insulation in the new buildings of Alaçatı, the gable roof application that the conventional houses of Alaçatı contain has energy sustainability effects. Since the gable roofs have a cavity space between their structures, they act as a buffer space between the interior and exterior environment. That speciality slows down the heat transfer speed (Figure 8).

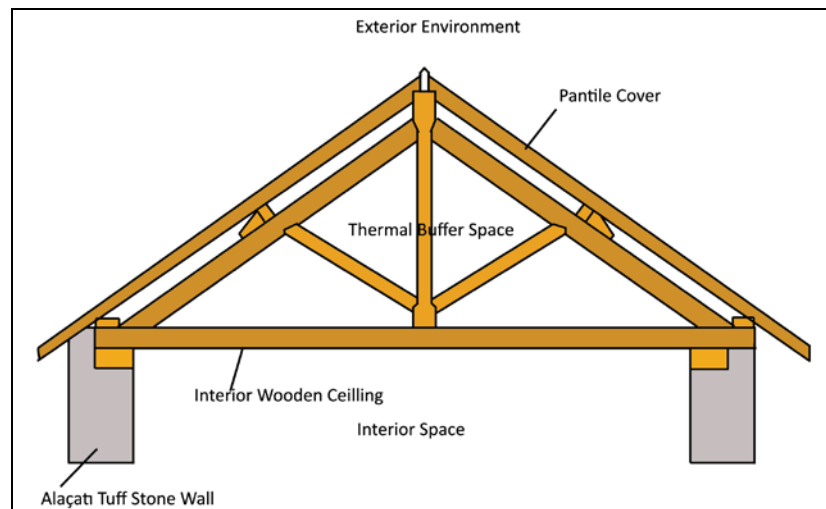


Figure 8. Schematic section of gable roof, works as a thermal buffer space (Archive, 2017).

In order to observe the effect of the vernacular gable roof application to the heating and cooling energy demand in comparison with the flat roof application that the new buildings contain in the area, the energy model of the both case were crosschecked. According to the energy values the traditional gable roof that the case model possess reduces cooling load respectably by %6.1, increases the heating load slightly by %0.6, and decreases the annual total energy demand by %2. It is observed that the gable roof helps cooling load in summer respectably, but it doesn't have much effect on heating load. It is because the flat roofs let the heat by the incident direct sun light in winters, while gable roof doesn't because of the thermal boundary effect of the cavity within.

#### *Integration of greenery*

The building has relation with greenery from the west side garden. The garden has tall deciduous trees that create shadow in the summer and let the sunlight through in the winter mornings. Regarding to that, the trees contribute to passive heating in winter by losing their leaves, and prevent the direct gain by blocking the sunlight by its leaves in summer, as depicted in Figure 9 (Chiras, 2002).

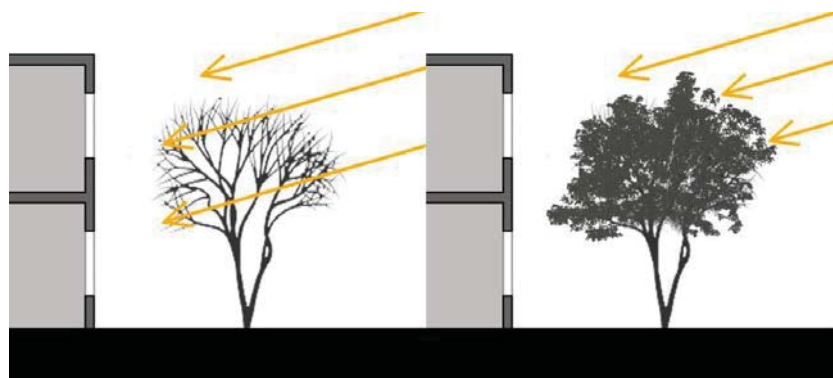


Figure 9. West garden winter and summer condition of the deciduous trees (Archive, 2017).

### *Interior space organisation*

The entrance of the building is from the north garden side, and the connection between the rooms is from the entrance hall and corridor in the first floor, which are located in the middle of the building. The rooms and all the other commonly used spaces in the day time are lined in the east and north, where the street and leisure garden are located. In the other façades there are WC, corridors, stairs, entrance hall are located, and the rooms don't have windows to south and west sides (Figure 10). It is observed that the organisation of the rooms was done concerning the prevention of the excessive heat gain in summer from the west and south façade.



Figure 10. Planning organisation (Seymen, 2010).

### *Orientation*

In the climate of Alaçatı vernacular houses tend to be longitudinal along the west and east axis, as this orientation let south sunrays inside in winter and prevent them in summer easily. Also this type of orientation leaves smaller area of façade to the east and west, where the sunrays are incident with narrow angle longer time in the day, which lead to excessive heating in summer. This type of orientation is harmonious with the south and north prevailing winds of Alaçatı, as the north and south façades are longer (Terim, 2011).

The orientation of the case building is just as the other vernacular houses of Alaçatı, longer façades are oriented to south and north, narrow façades are to the east and west. Yet the south façade of the building is adjacent with another building and the west and north façade is mostly under shade the whole year. The thick neighbourhood prevents the prevailing wind. In short, the orientation is proper for the climate, yet it cannot fully benefit because of the thick tissue of the neighbourhood.

## Findings

The evaluation of the sustainable design properties of the case hotel was done qualitatively and quantitatively in the previous section. The findings of the research are presented in the Table 1 below respectively to each sustainable design property of the case building.

Table 1. Results of the study.

Sustainable Design Criteria	Qualitative Analysis	Quantitative Analysis
Building form	The form and the neighbour building create a surrounded garden in the entrance. As the garden is shaded, it is liveable in hot summer days. The plan ratio of the hotel is 1:3.6, which exceeds the 1:1.7 – 1:3 range for the hot and humid climate (Olgyay, 1963).	The bay windows, which are the extrusions of the building form, decrease cooling load by %0.2, increase heating load by %5.3, and %3.1 in total annual. They are not effective, as they face the north and east side, where the sunlight is not incident during the year.
Sun exposure and shading strategy	The surroundings create shading for the building, and the building doesn't have any extra window shading elements, it is not needed.	The added shading elements decrease the cooling load in summer days by %3, and increase heating load in winter by %2. In the whole year they increase the total energy for heating and cooling very slightly by %0.1.
Natural ventilation	In the climate condition of Alaçatı natural ventilation deals great significance for passive cooling in summer (Terim, 2011).	Natural ventilation increases the heating load slightly by %0.3, decreases the cooling load effectively by %20, and decreases total annual energy consumption by %7.6.
Effect of neighbourhood and adjacency	The building is adjacent from the south side with another building, and the east and north side there are neighbour buildings in very close distance.	The effect of adjacency and the neighbourhood decreases heating load by %0.8 and the cooling load by %8.3 in hot season. It reduces total annual energy usage by %3.7.
Building materials	The building wall is load bearing masonry Alaçatı tuff stone, and the bay windows are made of wooden frame wall, which are the local materials of the region.	Comparing to the typical insulated wall, the local materials increase the heating load by %2.6, decrease the cooling load by %1.1, and increases the total annual energy by %1.2. The porous body of the stone lets the exterior air through.
Roof style	The building has two separate gable roofs, with a cavity inside. The cavity of the roofs acts as a thermal buffer and reduces the heat transfer speed.	The roofs reduce cooling respectively load by %6.1, increases the heating load slightly by %0.6, and decreases the annual total energy demand by %2, comparing to a flat roof.
Integration of greenery	The deciduous trees on the west side block sunlight in summer let them through in winter.	This criterion is not included in the quantitative analysis.
Interior space organisation	The entrance of the house is in the middle, from the north façade. The rooms are placed on the east, west and north façades, but on the west façade they don't have windows. The rooms are placed in concern with avoiding the direct sun.	This criterion is not included in the quantitative analysis.
Orientation	The building is longitudinal in the east-west axis, as it is suggested in the climate of the Alaçatı (Terim, 2011). Even though the orientation is proper for the climate of Alaçatı, because of the dense neighbourhood, the building is under shade most of the time of the year.	This criterion is not included in the quantitative analysis.

## Conclusion

Alaçatı is one of the significant tourism destinations of İzmir, Turkey, regarding to its cultural values, vernacular architecture and natural properties. The increasing tourism demand and the appeal of the vernacular architecture by the tourists led the emergence of the accommodation need and consequently conversion of the historical houses into boutique hotels. Hence the energy consumption by this growing number of hotels increases exponentially.

The present study deals with a hotel building that was converted from a 19<sup>th</sup> century vernacular house in the historical centre of Alaçatı. The study aims to reveal the condition of the sustainability futures of the hotel. In doing so, evaluation criteria are determined as building form, sun exposure and shading strategy, natural ventilation, effect of neighbourhood and adjacency, building materials, roof style, orientation, integration of greenery and interior space organisation. These evaluation criteria are employed conceptually and quantitatively. The quantitative method of the study is based on building energy modelling of the case hotel. The total annual energy consumption of the original case of the hotel is compared with the modified case energy model of the specific evaluation criteria.

The results showed that the bay windows and Alaçatı tuff stone wall do not play direct positive role in sustainability of energy consumption, while absence of window shading elements, natural ventilation, neighbourhood and adjacency, and gable roof cavity have major deal of influence on reducing the annual cooling and heating load. The general design attitude of the building in terms of sustainable architecture is avoiding direct gain by sun and creating shading against the excessive heat in summer, as it is observed in interior space organisation, leisure garden and the trees in the west garden. In addition, the orientation of the building is proper for the climate of the Alaçatı, yet it does not benefit from this, because of the shading effect of the neighbourhood.

The presented results of the case hotel denote that, the building contains positive and negative futures in terms of sustainability that are expected to guide other boutique hotels which have similar placement and orientation specialities. Further studies are needed to find ways for retrofitting the already existing hotels, and offering sustainable design guidelines for Alaçatı.

## References

- Archive (2017). *Alaçatı Photography and Graphics Archive of the Author*
- Banani, R., Vahdati, M.M., Shahrestani, M., Clements-Croome, D. (2017). The development of building assessment criteria framework for sustainable non-residential buildings in Saudi Arabia. *Sustainable Cities and Society*, 26, pp. 289-305.
- Busato, L. (2003). *Passive Cooling and Energy Efficient Strategies for Design of a Hotel on the Southern Coast of Pernambuco, Brazil*. MSc. London Metropolitan University
- Chiras, D.D. (2002). *The Solar House: Passive Heating and Cooling*. Vermont: Chelsea Green Publishing Company.
- El Demetry, I.M. (2014). Sustainable Architectural Design: Reviving Traditional Design and Adapting Modern Solutions. *Archnet-Ijar International Journal of Architectural Research*, 4 (1), pp. 99-110.
- Energyplus.net. (2017). Weather Data by Location - EnergyPlus. Available at: [https://energyplus.net/weather-location/europe\\_wmo\\_region\\_6/TUR//TUR\\_Izmir.172180\\_IWEC](https://energyplus.net/weather-location/europe_wmo_region_6/TUR//TUR_Izmir.172180_IWEC) [Accessed 3 Sep. 2017].
- Fernandes, J., Mateus, R. (2012). Energy Efficiency Principles in Portuguese Vernacular Architecture. In: *BSA 2012: 1st International Conference on Building Sustainability Assessment*, Porto, Portugal, 23 - 25 May 2012. Barcelos: Greenlines Institute for Sustainable Development.



- GhaffarianHoseini, A.H., Berardi, U., Dahlan, N.D., GhaffarianHoseini, A. (2014). What Can We Learn from Malay Vernacular Houses?. *Sustainable Cities and Society*, 13, pp. 157-170.
- Ibiyeye, A.I., Shari, Z., Jaafar, M.F.Z. (2016). Evaluating Natural Ventilation Provisions and Occupants' Ventilation Behavior in Five Terrace Housing Types in Putrajaya, Malaysia. *Archnet-Ijar International Journal of Architectural Research*, 10 (2), pp. 130-152.
- Jankovic, L. (2017). *Designing zero carbon buildings using dynamic simulation methods*. 2nd Edition. NewYork: Routledge Taylor & Francis.
- Khan, S.M. (2010). Sethi Haveli, an Indigenous Model for 21st Century 'Green Architecture'. *Archnet-Ijar International Journal of Architectural Research*, 4(1), pp. 85-98.
- Maatouk, K. (2007). Airflow Patterns and Stack Pressure Simulation in a High Rise Residential Building Located in Seoul. *Archnet-Ijar International Journal of Architectural Research*, 1(2), pp. 92-99.
- Okba, E.M. (2005). Building Envelope Design as a Passive Cooling Technique. In: *International Conference "Passive and Low Energy Cooling for the Built Environment"*, Santorini, Greece, 19 – 21 May 2005. Athens: Heliotopos Conferences
- Olgyay, V. (1963). *Design with Climate: Bioclimatic Approach to Architectural Regionalism*. New Jersey: Princeton University Press.
- Rubel, F., Kotteck, M. (2010). Observed and Projected Climate Shifts 1901–2100 Depicted by World Maps of the Koppen-Geiger Climate Classification. *Meteorologische Zeitschrift*, 19 (2), pp. 135-141
- Sadineni, S.B., Madala, S., Boehm, R.F. (2011). Passive Building Energy Savings: A Review of Building Envelope Components. *Renewable and Sustainable Energy Reviews*, 15, pp. 3617-3631.
- Salehi, A., Torres, I., Ramos, A. (2017). Assessment of Ventilation Effectiveness in Existing Residential Building in Mediterranean Countries: Case Study, Existing Residential Building in Portugal. *Sustainable Cities and Society*, 32, pp. 496-507.
- Seymen, S. (2010). Çitoğlu Evi Tash Mahal Oteli. *Ege Mimarlık*, 72 (1) pp. 38-41
- Terim, B. (2011). *Climatic Considerations in Traditional Built Environments: The Effect of Natural Ventilation on Thermal Comfort in Alaçati, Izmir, Turkey*. PhD. Izmir Institute of Technology
- Wang, L., Gwilliam, J., Jones, P. (2009). Case Study of Zero Energy House Design in UK. *Energy and Buildings*, 41, pp. 1215-1222.

# Spatial Mapping Analysis of Lost and Insurgent Spaces within the City of Durban

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**Abstract:** Durban, as well as all progressive cities, is prone to the effects of Globalization, economic stresses and poor city planning. Most cities were planned according to traditional urban design principles, which revolved around the concentric circle model developed by Ernest Burgess in 1925. Nowadays, due to rapid growth and a poor planning policies implementation in urban cities, the gap between the legal and illegal city has become more evident. New developments are moving further away from the city centre, causing sporadic growth and forming new nodes. This in turn leads to urban degeneration, lost and forgotten spaces within the city. Thus, urban poor claim the right to the city by occupying lost spaces within the urban framework.

Often mapping these lost spaces proves to be challenging to urban designers, Architects and planners who try to analyse and design ad hoc solutions. Understanding spatial qualities, socio-ecological ecosystems and economical systems, is key to create a resilient city. This paper explores an innovative research methodology of spatial mapping to analyse lost and insurgent spaces, as part of a broader PhD study. The research has two key objectives:

- To understand how space can be effectively captured and interpreted;
- To use spatial mapping as a key methodological approach in reinterpreting spaces towards creating a resilient city.

Empirical data was gathered by drone photography in a case study located within the city of Durban, to show the potential, advantages and disadvantages of spatial mapping within the city centre and periphery. Qualitative research methods (e.g. interviews and observations) are combined with spatial analysis, to fully understand how lost space can be reinterpreted and adapted. Therefore, the proposed research methodology allows for a more accurate (*lived 4D-maps*) mapping of scenarios affecting cities today.

**Keywords:** Urban Resilience, Insurgency, Lost Space, Spatial Mapping, drone photography

## Introduction

Many cities in the world have been planned according to traditional urban design principles, which revolved around the concentric circle model of Ernest Burgess (Pacione, 2001).

Nowadays, due to rapid growth and a poor planning policies implementation in urban cities, the gap between the legal and illegal city has become more evident. New developments are moving further away from the city centre, causing sporadic growth and forming new nodes. This in turn leads to urban degeneration, lost and forgotten spaces within the city. Therefore, urban poor claim the right to the city by occupying lost spaces within the urban framework. Often, mapping these lost spaces proves to be challenging to urban designers, Architects and planners who try to analyse and design ad hoc solutions. Understanding spatial qualities, socio-ecological ecosystems and economical systems, is key to create a resilient city.

As part of a broader PhD study under the umbrella of urban resilience, this paper explores an innovative research methodology of spatial mapping to analyse lost and insurgent spaces. The study seeks to understand how space can be more effectively captured and interpreted through a new spatial mapping that combines drone photography

and collaborative mapping. This mapping process can be used as a key methodological approach in reinterpreting spaces towards creating a resilient city.

Empirical data was gathered by drone photography in a typical informal settlement selected as a case study within the city of Durban. Qualitative research methods (e.g. interviews and observations) are combined with spatial analysis, to fully understand how lost space can be reinterpreted and adapted. The findings suggest that spatial mapping should be informed by collaborative mapping methods to produce an accurate 'lived' map which encompasses the general topography, spatial, social, economic and political dynamics of the chosen site. This combination of factors produces a map, which can reflect attributes that define space that often appears to be difficult to capture on a map. This new research methodology proposes a new perspective on capturing spatial attributes and defining space and allows for a more intuitive and comprehensive representation.

### **Urban resilience**

Resilience refers to the capability of individuals, social groups or socio-ecological systems, including towns and cities, to not only live with changes, disturbances, adversities or disasters but also to adapt, innovate and transform into new desirable configurations (Harris et al, 2014). Interestingly enough, the concept of resilience incorporates also the ability to self-organize and learn from past experiences and changing or adapting to new needs (Shaw, 2012).

The literature on *urban resilience* is new in the field of the built environment. In fact, the concept of resilience in the urban context was borrowed from Ecology studies referring to the capacity of ecological systems to cope with stresses and disturbances caused by external factors (Chmutina et al, 2016). Most cities around the world are adapting and challenging their urban frameworks to create resilient cities. The concept of Resilient city focus primarily on disaster management and vulnerability but more recently it has evolved to accommodate a multitude of factors that affect cities today. For example, Frantzeskaki (2015) defines Urban resilience as the capacity of urban systems, communities, individuals, organizations and business to recover and maintain their function and thrive in the aftermath of a shock or stress. However, usually these definitions analyse the city from an ecological perspective and do not embody the complexity of urban environments.

In South African cities, due to the apartheid planning, space has been predominantly defined by racial separation. Current literature fails to analyse urban resilience through urban segregation and it is that understanding that urban planners and architects need to acknowledge in order to create resilient cities.

Most cities are planned according to traditional urban design principles, which revolved around the concentric circle model developed by Ernest Burgess in 1975. That model was based on an outward expansion from the nuclei of the city. Burgess was not aware of the many factors that affect city growth (Pacione, 2001). Burgess model was a product of the industrialization era and focused around migrants' influx to the city.

Durban is evolving into the slightly newer model conceived by Vance Whites for the 21<sup>st</sup> century city. This model reflects society's changes, de-industrialization, and emergence of service economies, decreased family size and intervention by government in the process of urban growth (Pacione, 2001).

The future of cities should understand the complexity of systems that exist within it. Indeed, Urban spaces are created by social factors. Those spaces can be contested politically by marginal groups, who seek to define the space that best suits them. According to Pacione

(2001), the planner Louis Mumford failed to understand the societal factors that an urban space encompassed of, rather he read urban spaces as belonging to certain groups, not to the society as a whole. Many architects and planners followed suit; for example, Le Corbusier, Ebenezer Howard and Frank Lloyd Wright have not completely understood the complex factors affecting cities, and they have not considered growth and resilience. They set out to create new cities for societies, rather than adapting cities to the need for growth (Fitting, 2002).

Urbanization has caused cities to become leading centers of global consumption, production and pollution. Governance and Planning can be conceived as 'drivers of change' within the framework of sustainable urban transformation (McCormick et al, 2012). To make cities resilient to the demands of society as well as other factors, it is fundamental to incorporate those 'drivers of change'. This is a realization that multiple stakeholders, bodies of knowledge and societies allow the city to adapt and become resilient. The main challenge for resilient cities is to broaden the views and go beyond the mere ecological concept of resilience (mostly related to climate change and natural disasters) by understanding the social, cultural, economic and spatial factors that make up a city (Wikström, 2013). This will help cities to become more resilient and move forward to become a resilient state.

### **Insurgency and informality**

The theory of Insurgency, originated as a social theory defined by Henri Lefebvre (1996) as 'the right to the city' (Harvey, 2012). Architects and Planners have not foreseen this, as a threat affecting cities today. Insurgency occurs when periods of mass urbanization influence the mass influx of people to cities; therefore, cities become hosts of space to insurgent citizenship Holston, J. (2009). Lefebvre's notion of space encompasses much more than a physical space. He defines it as three spaces, namely 'perceived' spaces, 'conceived' spaces and 'lived' spaces. Perceived space is relatively objective for the viewer it is the daily environment and conceived space is the mental construction of space. 'Lived' space is the complex combination of perceived space and concealed spaces (Lefebvre, 1991). This definition of space by Lefebvre stitches the social constructs of space as well as the structural construction of space together. Therefore, planning of urban spaces in cities encompasses the various definitions of spaces that make up public, private and social spaces.

In South Africa, due to apartheid planning and policies, space was not encompassed to be a social factor that would allow for social integration. In particular, the spatial structure of the city of Durban, is not the result of planned growth or a vision of urban form, but instead of past race-based planning, and the extension of its boundaries over time to incorporate low-density urban settlements and adjoining farmlands. In addition, urban planning has been influenced by extreme topography. Thus, the city is spatially fragmented, vast, and complex, and economic uses are spatially segregated from residential uses (EThekweni, 2016). The static and heterogeneous spaces within the city, are often claimed by one group of the society, usually informal dwellers, who claim the 'right to the city' because of socio-economic opportunities and political factors. The spaces in the city that are susceptible to being taken over and claimed are the spaces in-between, wedges, redundant spaces, rooftops, voids and spaces below.

Informal settlements are considered a major concern for many urban city managements, as they pose health and environmental risks, both to the informal settlement dwellers and also to those living in the neighbourhoods. Those spontaneous and unplanned

settlements have been traditionally considered as 'urban substandard' offering housing to the urban poor and referring to the poor living conditions, health risks and environmental hazards (Sutherland et al., 2016). Informal settlements are characterised by self-help efforts, often illegal, and considered 'informal' as they do not align with prevailing regulations. In the self-help efforts residents make use of the limited resources available to them for the purposes of erecting shelter on interstitial or marginal land (Dovey and King, 2011) often close to economic, social or survival benefits. Interestingly enough, Roy (2011) suggests a more progressive interpretation of informal settlements as spaces of habitation, livelihood, self-organisation and politics. As stressed by Huchzermeyer (2011), informal settlements are complex, popular and spontaneous neighbourhoods offering an immediate response to housing and with their location critical for the socio-economic activities of the involved community. This concept moves away from the pathology of informal settlements, envisaging a potential in terms of dynamic places of living.

More in general Informality has been defined as the bedrock of African cities (Mitullah, 2007), since over half of African Urban population lives in informal settlements and far more is part of the so-called informal economy. Therefore, the development of African cities should approach those issues holistically, accommodating the informal economy and considering it in the actual planning and management of municipalities.

It is up to architects and planners to understand the concepts of insurgency and understand the complex elements that contribute to space, to plan buildings and neighbourhoods that can adapt to new needs and not be easily susceptible to be taken over and claimed. In South Africa, left over space is susceptible to insurgent citizenship, plots, abandoned buildings and wasted spaces have sprouted vibrant communities and groups.

There is a lack of knowledge and proper instruments able to define left over space and spaces within communities. A challenge for the Municipalities is, in fact, that the commonly used two-dimensional maps do not show clearly the various social spaces, environmental issues and land formations that can affect informal dwellers within a lost space. Therefore, alternative tools and mapping methods are required to produce a more realistic, 'lived' picture of the insurgent urban form.

### **Towards a new mapping methodology: the "4D Spatial Mapping"**

In the last decade, an increased interest and research on aerial vehicles technology led to an extensive application of drone photography to many different industries, such as agriculture, energy, construction, emergency response, military operations and even marine ecology (Ventura et al, 2016). Drones can be used both outdoor and indoor, even in very challenging environments and can be equipped with various sensors and cameras for doing intelligence, monitoring, and reconnaissance missions. (Hassanalian and Abdelkefi, 2017).

Nowadays, the lightweight Unmanned Aerial Vehicles (UAVs) provide an easy to use, financially accessible and efficient tool to collect a large amount of high-resolution images, which can be used as accurate spatial data on a day-to-day basis.

The present study proposes a new innovative research methodology that combines drone photography with a collaborative mapping process, with the direct involvement of affected inhabitants. The collaborative mapping approach deals with the lived experiences of communities within a specific area. The process of collaborative mapping can test problematic issues of policy when related to the built environment, and can reveal how they affect community lives and their responses to it. The response of mere stories that a person or community experiences and shares towards the mapping process, integrates the diverse



experiences, knowledge and moralities found in a place. The use of sketches done by the community in the mapping processes, provide multiple forms for expression, that allow communication of every-day experiences and sentiments that may be difficult to put into words (Stokols et al, 2013).

The first part of the proposed mapping process involves *sensing the place*; this is a transect walk to trigger individual perceptions and affective responses. This then will lead to body-space mapping that links storylines to place. This fundamental phase assists in understanding what underlying social, historical and personal connotations are associated to spaces that define or will help define space. Then, detailed maps are generated by means of the Unmanned Aerial Vehicle (UAVs) technology, with a 15 minutes drone-survey. This will give the community an accurate depiction of their settlement, as well as three dimensional views so that they can relate space if they do not understand it from a two-dimensional perspective. The drone-generated maps are then combined with the views of participants and many overlaps in a '*lived 4D-map*' that allows to fully understand and analyse the projected needs of the community and consider potential adaption to new requirements, through a resilience perspective. These maps provide not only a real-time representation of the settlement, but also reveal new, critical attributes (e.g. socio-economic, cultural, political dynamics, etc.), which refer to the invisible *lived* dimension (called '4D').

Photographic analysis plays a key role in the mapping and recording of lost space, as it is something, which cannot be theorized, but rather observed. The overall process of mapping, leading to this new "4D lived maps" has been summarized in the figure 1 below.

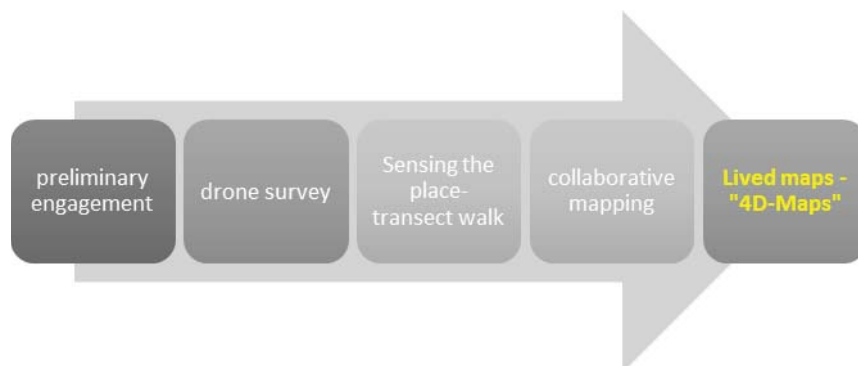


Figure 1. The stages of the "4D-Spatial Mapping" methodology. (Source: Govender and Loggia, 2017)

This study focuses on the city of Durban as an example of race-based (apartheid) city planning. The urban resilience solutions employed to combat spatial inequalities will be imperative for the researchers, in collaboration with the community, to develop an accurate depiction of an informal settlement as a two dimensional map, whilst encompassing the social, economic and political factors that define space.

When dealing with the resilience of the environment, a qualitative approach is used. Kevin Lynch in his book 'image of the city' uses mapping techniques, to analyse the physical attributes of the city experienced and understood by people (Groat and Wang, 2013). These maps were different from the usual maps used by municipality, planners and architects as it encompasses the social and cultural factors of the community. It involved interviews and sketches, overlaying these factors to produce an accurate representation of place. By that way, reading those maps it is possible to fully understand the social, physical and economic conditions of a site. In addition, Lynch's maps categorize important features found in cities,

paths, nodes, edges, landmarks and districts. Those mapping techniques have become an important tool to understand the complexities and dynamism of urban spaces where one object relies on the other, to exist in the urban fabric. This method has been employed by the researchers when capturing space in the form of a map to represent its components that make it up.

The present research relies on interpretation and perception of space. Often, municipalities, planners and architects fail to realise the social, economic and political fabrics that define space within an informal settlement, this then lead to poor planning and ineffective upgrading. The maps that are generally used to map informal settlements are often outdated and quite hard to understand. In addition, it would be too costly to have a live satellite image of the settlement. In response to this, the authors suggest the use of UAV -drone technology- coupled with a software called 3dsurvey, to map on a daily basis the sporadic growth that happens within an informal settlement.

Nowadays, Municipalities are facing big challenges in the attempt of understanding informal settlements and intervening accordingly. This is mainly due to poor participatory process employed when setting up community initiatives. For example, according to some municipal officials interviewed, the eThekweni Municipality has specific targets in terms of housing delivery and there is not real interest for community driven processes. They are facing the challenge of a massive backlog and participatory processes are time consuming and require more partnership between residents and local government. The lack of capacity, funding and technology has greatly contributed to this. Through various case studies and examples, failure by municipality to engage with the community and understand the spatial organizations that exist within an informal settlement has led to protests and rejections to any interventions aimed at informal settlements upgrading (Huchzermeyer, 2011).

Therefore, the process of collaborative mapping will aid in understanding how livelihoods and social spaces are recreated within lost and insurgent spaces.

### **Mapping a case study in Durban**

According to 2011 Census, almost 12% of all households in the Durban metropolitan area (eThekweni) live in informal settlements, with 29% renting their dwellings (HDA, 2013).

Hence, the authors selected a typical case study located in Avoca suburbs, in the Northern outskirts of Durban. The settlement was initially established in 1991, with the erection of few shacks. With the years, more people settled on the land, and a settlement grew to more than 200 households. Geographically, the settlement presents major topographical constraints, since is built up a steep hill on a relatively small piece of land that explain the high densities and typologies of the settlement. Due to the high density of the settlement, the access of emergency vehicles and roads with service delivery is very restricted. This informal settlement has taken over the lost space which has resulted from poor planning, left over space and insurgency. The settlement has proven to be sporadic, often springing new structures overnight. The Municipality has intervened in 2015 after a fire broke out and constructed temporary shelters. The settlement has given birth to a thriving community which has set up social, economic and political dynamics which are common to other communities within the city. The problem arises from the municipalities or outsiders perspectives of the community. There are no maps or spatial diagrams that explain the layout of the settlement, often an outdated map or a google earth image is the only data available.

Unfortunately, due to the sporadic nature of the settlement, under continuous change, the available maps are never up to date. Instead, by using drone imagery and reconstructing a 'lived' map of the settlement, the municipality and other professionals can understand spatial, political, economic and social layouts of the settlements. The map produced coupled with collaborative mapping techniques, can provide new perspectives for the community, municipality and other professional involved in the upgrading, to deal with factors affecting the settlement today.



Figure 2,3,4,5. The time line of insurgency taking place on the site from 2002-2017. (Source: Google earth)

### **Drone survey**

The test was done using a quadcopter drone, called the *dji mavic pro*. It utilizes a 4k camera which is a standard for a drone in this category.



Figure 6. The points taken to capture the images during the flight with an overlap of 65/65

The drone app called *Drone deploy* was used to chart the mission around the site. The researchers noted that the tallest structure was a tree which was roughly 6m high, however because of the slope of the site, the highest point was taken to avoid any obstacles for the drone, and the drone flew at a height of 59m. Once the mission was planned, the drone automatically flew the quadrant of the site capturing images as a top down view, the images were takes with a 65/65 overlap so that the stitching process would have less irregularities. Once the drone landed, the images were uploaded to a program called *3D- survey*, this enabled the stitching of the images together to form the overall map. The software also produces accurate contours and point cloud models, this is possible due to the geo-referencing on each picture taken by the drone. The survey took approximately 6:14 min with a speed of 15mph to complete and was measured to be 2 acres in length. The drone orbited at the end of the mission to gather additional images that can were used to gain clarity in the 3D-point reconstruction. It is noted that if a larger are is to be mapped, quadrants would have to be set up as the drone has a maximum flight time of 27min

between batteries, depending on the site area, this would have to be factored into consideration.



Figure 7 & 8. A google earth image (left) and the reconstructed drone map (right).

From the above two images, the google earth image shows less resolution and is not accurate in terms of imagery date, if the maps were to be printed from the google earth image, the resolution required to plan and analyse would distort the detail of the image. The reconstructed 3D-survey map shows immense detail and real-time imagery, the resolution of the picture is big enough to reprint and analyse detail, which would assist municipality and the community in understanding factors such as topography, climatic condition, spatial dynamics and density affecting the settlement. The detail is striking as compared to a google earth satellite image, and one can clearly see live imagery of the site, which could be used to analyse the sporadic nature of informal settlements. This is shown in the raw images captured in Figure 9&10.



Figure 9 &10. Raw photography from the drone.

### **Discussion**

The result of the proposed spatial mapping methodology is a 3D-map which captures the layering of the transect walk, community engagement and drone photography. Thus, this comprehensive representation of the multi-layer spatial dynamics of the community provides insights into the resilience of a community, in terms of adaptation, socio-economic and environmental factors, affecting them and the site.



The figure 11 shows the output of the spatial mapping process. In the legend below are listed all the key environmental and socio-economic attributes that have been mapped during the transect walk with a community leader.

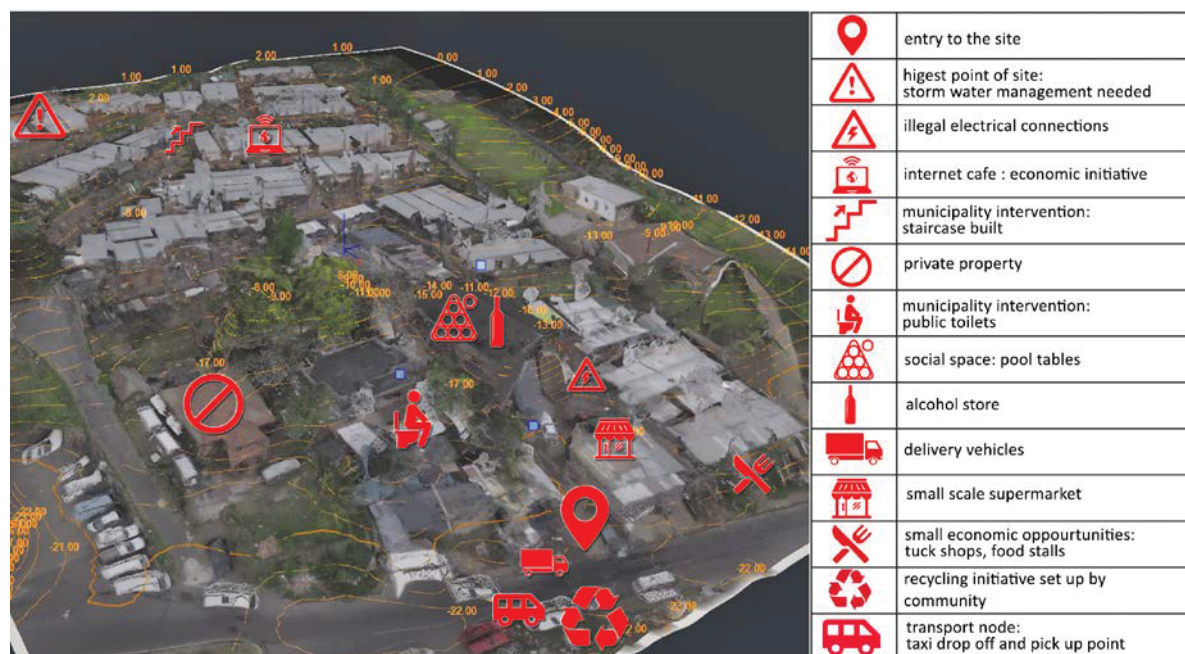


Figure 11. Spatial mapping of the case study.

This comprehensive map can be used as the foundation for the collaborative mapping exercise, whereby the community members are able to identify the houses and the other attributes more intuitively, since they can see also 3D geo-referenced images of the same. The final outcome of this spatial mapping process in this case study is a '4D-map', where the 4<sup>th</sup> dimension is the representation of the socio-economic dynamics occurring in the settlement. This enables the municipal officials and the other professionals involved in the collaborative mapping, to understand what makes up the community and what factors need to be addressed. In fact, the map recreates a 'lived experience' of the settlement.

## Conclusion and recommendations

The present study proposes a new methodology for a more comprehensive, real-time and in-depth spatial mapping of the city, which captures the attributes of resilience of a community. By combining drone photography with collaborative mapping, the authors seek to develop 'lived' imagery of a place, which includes geo-referenced data, 3D-workable maps, contours, site sections and height analysis.

In fact, the conventional methods of mapping used by Municipalities, based on GIS systems and aerial photography, are more expensive and require technical training. Moreover, when those methods are associated to participatory processes, only the trained



professionals, rather than the unskilled public, are able to understand them. This can create challenges in the collaboration between the different stakeholders.

Further studies will focus on testing this innovative methodology in other case studies located in the city center, where the effects of insurgency are difficult to understand and capture. It is expected that local governments and professionals can use this innovative mapping process as a key methodological approach in reinterpreting spaces towards creating a resilient city.

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## References

- Chmutina, K., Lizarralde, G., Dainty, A., & Boshier, L. (2016) Unpacking resilience policy discourse. *Cities*, 58 pp.70-79.
- Dovey, K., & King, R. (2011). Forms of informality: morphology and visibility of informal settlements. *Built Environment*, 37(1), 11–29.
- Ethekwini Municipality, (2016). EThekwini Built Environment Performance Plan (BEPP) 2016-2017. [http://devplan.kzncogta.gov.za/idp\\_reviewed\\_2016\\_17/IDPS/Durban/Adopted/eThekwinini%20BEPP%202016-17%20%20.pdf](http://devplan.kzncogta.gov.za/idp_reviewed_2016_17/IDPS/Durban/Adopted/eThekwinini%20BEPP%202016-17%20%20.pdf)
- Fitting, P.(2002) Urban Planning/Utopian Dreaming: Le Corbusier's Chandigarh Today, *Utopian Studies*, 13, (1), pp. 69-93
- Frantzeskaki, N. (2016). URBAN RESILIENCE. A concept for co-creating cities of the future. DRIFT, Erasmus University Rotterdam, The Netherlands.
- Available: [http://urbact.eu/sites/default/files/resilient\\_europe\\_baseline\\_study.pdf](http://urbact.eu/sites/default/files/resilient_europe_baseline_study.pdf)
- Groat & Wang, D, L. (2013). Architectural Research Methods, John Wiley & sons Inc., Hoboken, New Jersey, USA
- Hancock, M.E. (2005). Architecture of Memory. *The Public Historian*, 27(4), p.79
- Harrison, P., Bobbins, K., Culwick, C. , Humby,T.L., La Mantia, C., Todes A. and Weakley, D. (2014). Urban Resilience Thinking for Municipalities. University of the Witwatersrand, Gauteng City-Region Observatory
- Harvey, D. (2012). Rebel Cities, from the right to the city to the urban revolution, Verso, The United States of America.
- Hassanalain, M. and Abdelkefi, A. (2017). Classifications, applications, and design challenges of drones: A review, *Progress in Aerospace Sciences*, 91, pp.99-131
- Holston, J. (2009), Insurgent Citizenship in an Era of Global Urban Peripheries. *City & Society*, 21 (2), pp. 245-267. DOI: 10.1111/j.1548-744X.2009.01024.x
- The Housing Development Agency (HDA). (2013). KwaZulu-Natal: Informal settlements Status. RESEARCH SERIES PUBLISHED BY THE HOUSING DEVELOPMENT AGENCY
- Huchzermeyer, M. (2011). Cities with 'Slums': From informal settlement eradication to a right to the city in Africa. Claremont: UCT Press.
- Jabreen, Y, (2011). Planning the resilient city: concepts and strategies for coping with climate change and environmental risk. *Cities*, 31, pp. 220-229
- Lefebvre, H. (1991). The production of space. Oxford, OX, UK, Blackwell.
- Lynch, K. (1960). The Image of the City. Massachusetts: MIT Press.
- McCormick, K., Neij, L., & Anderberg, S. (2012). Sustainable Urban Transformation and the Green Urban Economy. In R. Simpson, & M. Zimmermann (Eds.), *The Economy of Green Cities: A World Compendium on the Green Urban Economy* Springer.

- Pacione, M. (2001). Models of Urban Land Use Structure in Cities of the Developed World. *Geography*, 86, (2), pp.97-119
- Poon, B.H.S. (2001). Buildings Recycled, City Refurbished. *Journal of Architectural Education*, 54(3), pp.191-194
- Rahnama, M. , Roshini, P., Hassani, A., Hossienpour, S. (2012). Use Principles of New Urbanism Approach in Designing Sustainable Urban Spaces. *International Journal of Applied Science and Technology*, 2(7), pp. 195-202
- Roy, A. (2011), Slumdog Cities: Rethinking Subaltern Urbanism. *International Journal of Urban and Regional Research*, 35: 223–238. doi: 10.1111/j.1468-2427.2011.01051.x
- Sutherland C., Braathen E., Dupont V. and Jordhus-Lier D. (2016). Policies towards substandard settlements. In: Dupont V., Jordhus-Lier D., Sutherland C. and Braathen E. "The politics of slums in the Global South". 2 Park Square, Milton Park, Abingdon, Oxon OX14 4RN: Routledge. pp. 48-78.
- Shaw, K. (2012). The rise of the resilient local authority? *Local government studies*, 38(3), pp. 281–300.
- Stokols, D., R. Perez Lejano, and J. Hipp. 2013. Enhancing the resilience of human–environment systems: a social–ecological perspective. *Ecology and Society* 18(1): 7. <http://dx.doi.org/10.5751/ES-05301-180107>
- Yung, E H.K & Chan, H.W. (2012). Implementation challenges to the adaptive reuse of heritage buildings: Towards the goals of sustainable, low carbon cities. *Habitat International*, 35, pp. 352-361
- Ventura D., Bruno M., Jona Lasinio G, Belluscio A., Ardizzone G. (2016). A low-cost drone based application for identifying and mapping of coastal fish nursery grounds. *Estuarine, Coastal and Shelf Science*, 171, pp. 85-98.
- Wikström, A. (2013), the Challenge of Change: Planning for Social Urban Resilience. An analysis of contemporary planning aims and practice. Unpublished masters dissertation in urban and regional planning, Department of Human Geography, Stockholm University.

# The Impact of Adopting Building Information Modeling (BIM) in the Construction Industry

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## Abstract:

The Architecture, Engineering, and Construction (AEC) industry is recently facing a major transformation due to adopting Information Technology (IT) and digital technology in the past three decades. Building Information Modeling (BIM) has been considered as one of this advanced technology which leads a significant shift within the AEC industry since traditional 2D tools are not fully integrated, or promote a complete collaboration. 2D tools can only manage length and width values, which result in inefficiency in the industry productivity. On the other hand, BIM provides virtual models in virtual environments with integrated data, these models can assist in project management process through projects life cycle phases. Therefore enhance its productivity and reduce possibilities of errors and waste. This paper discusses the impacts of adopting advanced methods of BIM and its role as a project management tool for early pre-construction phase, its benefits, and barriers to adopting these levels in the construction industry. It also investigates the BIM adoption rate in the Egyptian construction industry, by collecting data from 125 multiple stakeholders in Egypt using an online questionnaire to assess knowledge, and the use of BIM in Egypt. The results indicates that the adoption rate of BIM technology is still low and needs to be improved. However, the participants demonstrated a positive awareness of the significance of using BIM for the future construction projects. The research result also reveals two critical barriers in BIM adoption, technology-related barriers, and process-related barriers. The importance of the research is to optimize adopting advanced BIM tools in construction projects from pre-construction level, as well as understanding barriers limiting a complete implementation of BIM in future construction projects, in order to achieve the main purpose of this research which is knowing where BIM should be heading and how the AEC industry can benefit from its advantages.

**Keywords:** Building Information Modeling (BIM), Pre-Construction, Construction Industry, Barriers, Project Management

## Introduction

During the recent three decades, the construction industry has seen a significant improvement of the utilization of Information Technology (IT), as the advances in IT have been used as a tool to manage coordination issues which take place during the construction process, so as to enhance its productivity. (Froese, 2010). The most recent and promising tool which can represent this improvement of adopting Information Technology (IT) in the construction industry is the use of Building Information Modeling (BIM), it can be defined as the process of using IT for sharing data, evaluation, collaboration, and management of virtual model through project's construction process.

BIM refers to the improvement of using computer-generated 3D models to simulate a facility's life cycle, including planning, design (pre-construction), construction, sustainability, and operation and maintenance (post-construction). This model provides consistent and coordinated views, including reliable information for each view; this saves time and cost since each view is coordinated through the built-in intelligence of the model. (Hergunsel, 2011). BIM also allows users to test a lot of decisions at an early stage, and bump into

problems early, so that they can go in another direction in order to avoid potential problems. (Suermann, 2009).

However, the construction industry is considered as one of the largest industries around the world, also as it is well known, the success or failure of every construction project can be measured in terms of four variables: costs, time, quality, and safety. (Adrian, 1995). Yet a quite large amount of the gross spending in the construction industry is a waste due to deficiencies in sharing relevant information, lack of experience, and expertise. Hence Information Technology (IT), and BIM tools including digitization, simulation, and sharing information have been adopted in the construction industry, its productivity has a significantly increased. There are many previous and current research has been focusing on the benefits of adopting BIM and its tools in the construction industry, these benefits have proven to be a value to the industry. However, these tools have some setbacks which prevent a successful and complete adoption of BIM in the construction industry. Thus, there is a pressing need to focus on the comprehension of how BIM can be applied to construction projects, on pre-construction phase, and improving its adoption rate, also there is a need to understand, analyze, and evaluate the new level of BIM which is level 3 (known as Open BIM). Moreover, analyzing the different barriers and challenges which limiting the adoption process, and how they can be overcome, in order to achieve a significant increase in the construction management productivity rate and to make adopting BIM in the construction industry more effective and accessible.

### **BIM for the Construction Industry**

Alvar Aalto stated that “Nothing is a danger in Architecture as dealing with separate problems if we split life into separated problems; we split the possibilities to make good building art” (Borson, 2010). Construction projects are becoming much more difficult and complex to manage, with several independent professionals involved in different phases, one complexity is the lack of the sharing information between the separated construction main phases; pre-construction, onsite construction, and post-construction, as well between various practitioners who are involved in the construction process. As a response to this complexity, and over the past three decades, advances in Information Technology (IT) and Digitalization, especially in Building Information Modeling (BIM), has made construction professionals to rethink the way of information sharing of construction project and innovative approaches for generating and managing building data during its lifecycle (Lee, Yu, & Jeong, 2014).

Despite a lot of studies on BIM over the past years, it has been argued that the construction industry continues to lag behind in BIM development. The construction industry has a slow increase in its productivity compared to other industries, therefore Building Information Modeling (BIM) has been presented by numerous of professionals and researchers as a tool to deal with this issue, but even while the using of BIM in AEC industry has proceeded for a long time, its adoption rate in construction process is still moderate. (Lindblad, 2013). With advancements in technology every day, the use of BIM has expanded from mere 3D modeling to 4D, 5D, 6D and 7D modeling information which represent time and scheduling, cost, LEED evaluation, operation & maintenance respectively, which managing planning, design, and pre-construction phase, onsite activities, building facility maintenance and assessment of its life cycle.

The most recent improvement of BIM technology is (Open BIM), also known as Integrated BIM (iBIM) or BIM Level 3, shown in Figure 1, which is a single, shared model with professionals from different disciplines who are involved in construction projects, they can access that same model and modify it, so that (Open BIM) enables a fully, early, and open collaboration, this collaboration can avoid any potential risk for conflicting data, optimize of schedule and cost, reduce future waste during projects life cycle, by detecting clashes and predicting problems, which increase productivity, efficiency, and quality of the construction industry. However, BIM new levels are not yet widespread in several countries around the world due to many different barriers which prevent an effective and complete adoption of BIM in the construction projects.

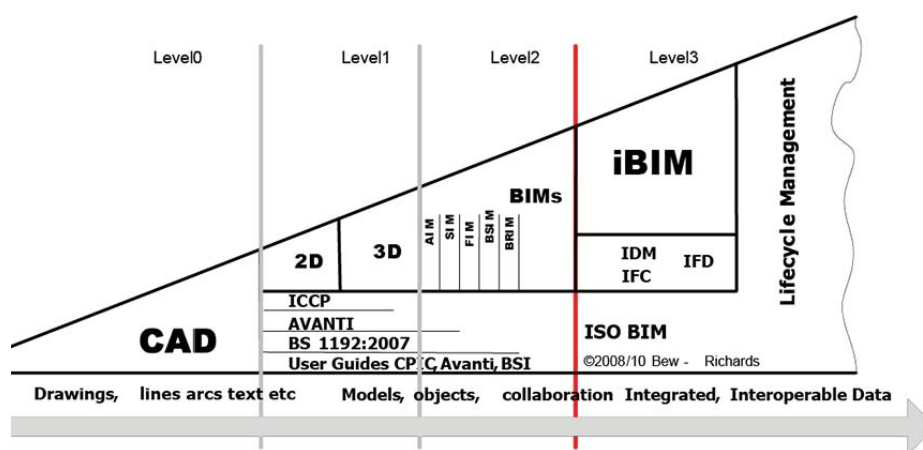


Figure 1. BIM levels.

### A Recent View on the Implementation Rate of BIM in Construction Projects

Several research and reports during the last few years focus on using BIM for the AEC industry, these studies reveal number of interesting facts, Research and Market has declared their report "Market Insight – Building Information Modeling (BIM) in the Global Construction Market" in June 2016, this report is based on a survey of over 1000 firms and professionals involved in the construction industry around the world to evaluate the value and barriers of implementing BIM in construction projects, to obtain an understanding of the levels of BIM using currently and likely to be used in the future in the international market. According to the survey results, 41% of the participants do not use BIM in their construction projects currently, 29% are applying it, 20% are piloting the software without real use, and 10% have a future plan to use BIM within a year. The results show that the adoption of BIM in construction projects is on the schedule for participates in the industry; however, it has not yet achieved. (MarketsandResearch, 2016).

Another report conducted by Markets and Markets demonstrated that "the global Building Information Modeling (BIM) market is expected to reach USD 7,946.5 million by 2020, at a Compound Annual Growth Rate (CAGR) of 13% from 2015 to 2020". This report provides a detailed information based on analysis of the Building Information Modeling (BIM) market globally based on main factors such as; users, function, type, and geography." (MarketsandMarkets, 2015). With advancements in BIM tools, the global Building



Information Modeling (BIM) market is expected to garner revenue of \$11.7 billion by 2022, registering a CAGR of 21.6% during 2016 -2022. (MarketIntelReports, 2016).

### BIM as a Construction Project Management Tool

Building Information Modeling (BIM) can be considered as a management tool rather than a technical tool, its function goes beyond its design capability. In fact, BIM can be translated in two ways, either Building Information Modeling or Building Information management, since BIM has its long-term application in the field of project management. However, adopting BIM as a management tool at the pre-construction phase (Schematic Design, Design Development, and Construction Documents) will optimize its benefits on the project life cycle as shown in Table 1. The pre-construction stages are the most critical phase of the decision-making process that will save cost, time, and resources via clash detection, and so improve the quality of project delivery, as it supports the concept of Integrated Project Delivery (IPD) which is an incoming project delivery approach. Therefore, stakeholders can take advantage of adopting BIM at early design stages.

Table 1. Shows BIM applications in pre-construction phases

Schematic Design (SC)	Design Development (DD)	Construction Documents (CD)
Design options analysis according to existing conditions.	3D models analysis (building performance, energy consumption, structural analysis)	4D models analysis (Scheduling, clash detection) 5D analysis (cost estimation)

Building Information Modeling (BIM) approach is strongly matched with Integrated Project Delivery (IPD) system, Thus, BIM can be considered as an effective and powerful tool in project management process, where its capabilities correspond to Project Management Body of Knowledge (PMBOK) knowledge areas, and the role and nature of every function are similar. For instance, BIM can handle project management planning, cost management, time management, quality management, etc. (Fazli, 2014) Table 2 illustrates the similarities between BIM and PMBOK knowledge areas.

Table 2. Similarities between BIM functions and PMBOK knowledge areas.

PMBOK Knowledge Areas	BIM Functions
Integration Management	IPD (Integrated Project Delivery)
Scope Management	Element-Base
Time Management	4D
Cost Management	5D
Quality Management	Clash Detection
Human Resources Management	Collaboration
Communications Management	Communication
Risk Management	Constructability
Procurement Management	Quantity Take-off
Stakeholder Management (new in 5th edition)	

The most significant functions of BIM is its ability to estimate and manage time and cost, what is known as 4D and 5D respectively. The significance of these two functions is that they can be utilized at the early design stages, also they can assist in the decision-making process and its consequences. 4D and 5D are similar to time management and cost management in PMBOK. (Rokooei, 2015) Another ability of BIM is detecting clashes and conflicts, which similar to quality management in PMBOK, it can recognize and analyze conflicts that reflected in the quality of the construction projects. Therefore, BIM can be considered as an effective method of project management process corresponding to PMBOK.

### Adopting Building Information Modeling (BIM) in the Egyptian Construction Industry

Lately many governments around the world encourage adopting BIM tools for the construction industry, one example; The European Parliament recently recommended that the use of BIM be included in the Public Procurement Law of the European Union. (Nemetschek-AG, 2016). However, BIM market is expected to increase at a significant rate due to the support of governments, the Egyptian government does not promote the adoption of BIM public construction work. This paper intends to look at the current practice of adopting BIM in Egypt.

### Methodology

An online survey questionnaire was sent to various stakeholders providing construction services in Egypt, this survey was designed to obtain and investigate data about their knowledge and experience related to implementing BIM technology with a series of questions based on the objectives of the paper, and the survey targeted 120 stakeholders, the response rate was 19%.

Questionnaire Section 1: Knowledge of BIM technology, this section was to assess the knowledge of BIM technology, its tools, and its benefits for the pre-construction phase.

Questionnaire Part 2: Technical practice and experience, this sections aimed to assess the technical knowledge of BIM software, the frequency of practice and the main barriers of adopting BIM in the construction projects.

### Findings

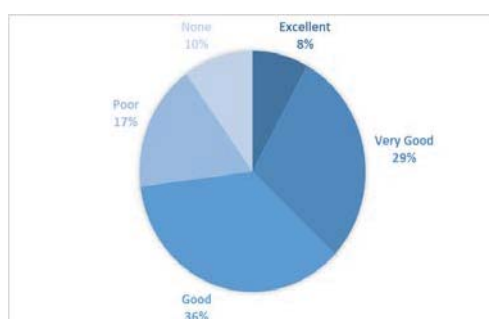


Figure 2. BIM knowledge

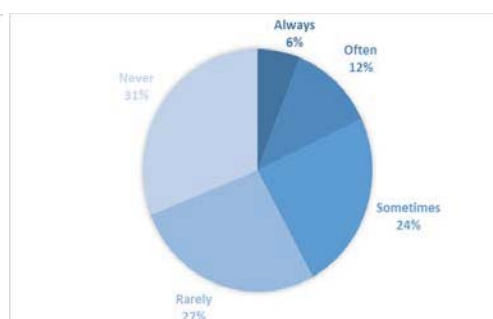


Figure 3. Frequency of BIM practice

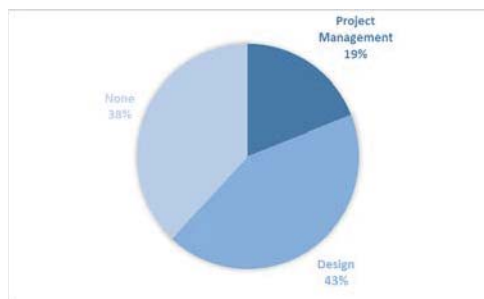


Figure 4. Scope of using BIM

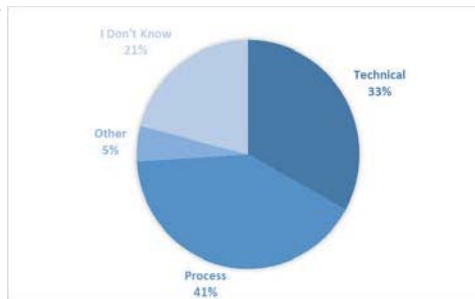


Figure 5. Barriers to adopting BIM

### Barriers to BIM Adoption in Construction Projects

Although the numerous benefits of BIM tools for project management process, they are many barriers to adopt BIM as a project management tools at the early design stages, these barriers can be divided into two categories: technology-related barriers, and process-related barriers. (Salman Azhar, 2012). One of the technology-related barriers is that BIM is a shared model that requires multiuser access for the project's stakeholders. Since there are no standards for integrating information and management, each participant follows its own standards and formats which leads to inaccurate and inconsistent BIM model. While protecting the BIM model data as a copyright and the ownership issues is considered as process-related barriers, as well taking the responsibility of the model data and its update, in other words, the absence of a definition for professional responsibilities. Lack of technical skills is also a significant barrier and the cost of its implementation challenges. Thus, before BIM technology can be fully adopted in the construction industry, these barriers need to be identified and allocated in order to find creative solutions that allowed the construction industry to take full advantages of adopting BIM as a design and project management tool from the projects first stages.

### Conclusion

BIM is a promising tool for the AEC industry due to its various functions and applications at the construction projects different phases, from the early design and pre-construction stage to facilities management and maintenance. However, the rate of its movement is slightly progressing. Therefore, is a pressing need to increase awareness and understanding of BIM tools and its benefits for the construction industry, as well as the business value of BIM. There is a large lack of knowledge of BIM and its applications at the pre-construction phases throughout the lifecycle of construction projects; there is also a lack of technical skills that are needed for adopting BIM in the construction industry, this lack of knowledge and skills of BIM is leading to a slow adoption in the construction industry, which wastes a lot of resources, time, money, and projects quality.

### References

- Adrian, J. (1995). Construction Productivity: Measurement and Improvement. Champaign, Illinois, USA: Stipes Publishing.
- Bryde, D., Broquetas, M., & Volm, J. M. (2012). The Project Benefits of Building Information Modelling (BIM). International Journal of Project Management, 10.

- Froese, T. M. (2010). The Impact of Emerging Information Technology on Project Management for Construction. *Automation in Construction*, 8.
- Groat, L. N., & Wang, D. (2013). *Architectural Research Methods*. USA: John Wiley & Sons Inc.
- Hartmann, T., Meerveld, H. V., Vossebeld, N., & Adriaanse, A. (2012). Aligning Building Information Model Tools and Construction management Methods. *Automation in Construction*, 9.
- Hergunsel, M. F. (2011). *Benefits of Building Information Modeling for Construction Managers and BIM Based Scheduling*. Worcester, Massachusetts, USA: Worcester Polytechnic Institute.
- Lee, S., Yu, J., & Jeong, D. (2014). BIM Acceptance Model in Construction Organizations. *Journal of Management in Engineering*, 13.
- Lindblad, H. (2013). *Study of the Implementation Process of BIM in Construction Projects*. Stockholm, Sweden: KTH Architecture and Built Environment, Royal Institute of Technology.
- Nemetschek-AG. (2016). *BIM – Intelligent Model and Consistent Processes*. Germany: NEMETSCHKE AG.
- Salman Azhar, M. K. (2012). Building Information Modeling (BIM): Now and Beyond. *Australasian Journal of Construction Economics and Buildings*, 12.
- Suermann, P. C. (2009). *Evaluation the Impact of Building Information Modeling (BIM) on Construction*. Florida, USA: University of Florida.
- Wong, J., & Yang, J. (2010). Research and Application of Building Information Modelling (BIM) in the Architecture, Engineering, and Construction (AEC) Industry: A Review and Directions for Future Research. *Queensland University of Technology*, 11.
- Azhar, S. (2011). Building Information Modeling (BIM): Trends, Benefits, Risks, and Challenges for the AEC Industry. *Leadership and Management in Engineering*, 12.
- Babič, N. Č., Podbreznik, P., & Rebolj, D. (2010). Integrating resource production and construction using BIM. *Automation in Construction*, 5.
- Barlish, K., & Sullivan, K. (2012). How to measure the benefits of BIM — a case study approach. *Automation in Construction*, 11.
- Grilo, A., & Jardim-Goncalves, R. (2010). Value proposition on interoperability of BIM and collaborative working Environment. *Automation in Construction*, 9.
- Jung, Y., & Joo, M. (2011). Building Information Modeling (BIM) framework for practical implementation. *Automation in Construction*, 8.
- Migilinskasa, D., Popovb, V., Juocevičius, V., & Ustinovichiusd, L. (2013). The Benefits, Obstacles, and Problems of Practical BIM Implementation. *Procedia Engineering*, 8.
- Ning Gu, K. L. (2010). Understanding and facilitating BIM adoption in the AEC industry. *Automation in Construction*, 12.
- Peterson, F., Hartmann, T., Fruchter, R., & Fischer, M. (2011). Teaching construction project management with BIM support: Experience and lessons learned. *Automation in Construction*.
- Porwal, A., & Hewage, K. N. (2013). Building Information Modeling (BIM) partnering framework for public construction projects. *Automation in Construction*, 11.
- Sacks, R., Radosavljevic, M., & Barak, R. (2010). Requirements for building information modeling based lean production management systems for construction. *Automation in Construction*, 16.
- Fazli, A., Fathi, S., Enferadi, M. H., Fazli, M., & Fathi, B. (2014). Appraising effectiveness of Building Information Management (BIM) in project management. *Procedia Technology*, 10.
- Doumbouya, L., Gao, G., & Guan, C. (2016). Adopting of the Building Information Modeling (BIM) for Construction Project Effectiveness: The Review of BIM Benefits. *American Journal of Civil Engineering and Architecture*, 6.
- Rokooei, S. (2015). Building Information Modeling in Project Management: Necessities, Challenges, and Outcomes. *Procedia Social and Behavioral Sciences*, 9.
- Borson, B. (2010, December 1). Design Quotes. Retrieved October 25, 2016, from Life of An Architect: <http://www.lifeofanarchitect.com/design-quotes/>
- Bryde, D., Broquetas, M., & Volm, J. M. (2012). The Project Benefits of Building Information Modelling (BIM). *International Journal of Project Management*, 10.
- El Nasser, F. A. (2015). *Dialectics of Architecture and Technology (The Impact of Technological Development on Architectural Formation)*. Cairo, Egypt: Cairo University.
- Froese, T. M. (2010). The Impact of Emerging Information Technology on Project Management for Construction. *Automation in Construction*, 8.
- Groat, L. N., & Wang, D. (2013). *Architectural Research Methods*. USA: John Wiley & Sons Inc.
- Hartmann, T., Meerveld, H. V., Vossebeld, N., & Adriaanse, A. (2012). Aligning Building Information Model Tools and Construction management Methods. *Automation in Construction*, 9.

- Hergunsel, M. F. (2011). Benefits of Building Information Modeling for Construction Managers and BIM Based Scheduling. Worcester, Massachusetts, USA: Worcester Polytechnic Institute.
- Lee, S., Yu, J., & Jeong, D. (2014). BIM Acceptance Model in Construction Organizations. *Journal of Management in Engineering*, 13.
- Lindblad, H. (2013). Study of the Implementation Process of BIM in Construction Projects. Stockholm, Sweden: KTH Architecture and Built Environment, Royal Institute of Technology.
- MarketIntelReports. (2016). World Building Information Modeling (BIM) Market - Opportunities and Forecasts, 2015 - 2022. USA: [www.marketintelreports.com](http://www.marketintelreports.com).
- MarketsandMarkets. (2015). Building Information Modeling Market by End-User (Architect, contractor, owner), Type (Software, Services), Vertical (Commercial, Residential, Educational, Industrial, Healthcare) and Geography - Analysis and Forecast to 2015 - 2020. India: [www.marketsandmarkets.com](http://www.marketsandmarkets.com).
- MarketsandResearch. (2016). Market Insight - Building Information Modeling (BIM) in the Global Construction Market. Ireland: [www.researchandmarkets.com](http://www.researchandmarkets.com).
- Nemetschek-AG. (2016). BIM – Intelligent Model and Consistent Processes. Germany: NEMETSCHKE AG.
- Suermann, P. C. (2009). Evaluation the Impact of Building Information Modeling (BIM) on Construction. Florida, USA: University of Florida.

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# Reexamining the Architectural Design Process from a Sustainable Point of View

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**Abstract:** Currently, many of the architecture firms are putting more emphasis on sustainability in order to enhance building performance and reduce the Life-Cycle Cost (LCC) of buildings. The design process plays a key role in delivering a socially, economically and environmentally successful sustainable building within budget and on schedule. The main goal of this study is to investigate the integration of sustainability into the design process. Previous studies on sustainable design processes are collected to produce a flowchart model that provides a systematic guidance to implement sustainability through the integrated project delivery system. Analysis including feedback from experts in the field indicated that the sustainable design process is complicated and nonlinear. It consists of multiple iterative processes to ensure that the sustainability goals are implemented. Utilizing Building Information Modelling (BIM), Integrated Design Process (IDP), and involving design charrette are significant as they decrease the discrepancies and maintain the integration of the building systems. Managing and maintaining strong communication among design team members are essential prerequisites for the success of the proposed model.

**Keywords:** Sustainability, process, BIM, design, model

## Background

The building design process is a systematic method that consists of interrelated activities and decisions. Many of these activities are overlapping, sequential or simultaneous and most are iterative. Also, these activities require a multidisciplinary team of professionals (Architects, structural engineers, mechanical engineers, interior designers, and so on), which needs a robust communication and coordination across the team.

Existing literature describes the traditional design process as a linear and fragmented processes due to the untiring contributions of the design team members (Kibert, 2016; Farias, 2015; Farias, 2013; Robichaud and Anantatmula, 2010; Almohaimeed, 2009). Due to the nature of this practice, any change could delay the process, lessens the quality and increases the cost significantly.

Some architectural firms have started to apply sustainability principles in order to reduce the environmental impact and enhance the functionality of buildings. This is because recent study has shown that buildings consume a large amount of energy; about 50% of the material resources are taken from nature and 40% of energy is utilized during the construction and operation of unsustainable cooling and heating system (Othman and Nadim, 2010). Focusing on certain tools, such as installing solar panels or roof gardens does not necessarily ensure significant improvements in sustainability. Therefore, a systematic and holistic view of Sustainable Design Process (SDP) should be used throughout the design process.

This study aims to discuss the incorporation of sustainability into the design process by using a flowchart technique as a basis. It provides a practical guidance on how to implement a sustainable design process taking into account Integrated Project Delivery (IPD).

## Related Literature

The SDP is defined as “the overall quality of the process that enables the delivery of sustainable buildings.” (Häkkinen and Belloni, 2011). It is one means for delivering a successful sustainable high-performance building within budget and on time (Horman et al., 2004).

According to Wu and Issa (2013), the optimal delivering method for sustainable building is an Integrated Project Delivery (IPD), which they define as “a collaborative alliance of people, systems, business structures, and practices that employ a process that harnesses the talents and insights of all participants to optimize project results” (Farias, 2013). It provides better value for the client, cuts waste and increases efficiency throughout all design phases, fabrication, and construction works. This method incorporates several concepts, such as integrated process, lean construction, Building Information Modelling (BIM), and other techniques (Kibert, 2016).

Several studies have been conducted to investigate relevant aspects of SDP. Most of these studies focussed on qualitative-descriptive data to describe the process. Robichaud & Anantatmula (2010) suggest some modifications to the traditional design process, in order to improve the cost-efficient green projects delivery. The study presented a comparison matrix between the traditional practice vs. a green building management approach in parallel. The matrix included tasks and activities listed in linear process while disregarding the overlapping and concurrent tasks. Hence, the integration of the SDP is missing.

Farias (2013, 2015) integrated three techniques (BIM, IDP, and building energy simulation (BES)) into design process to produce a sustainable design. However, Farias’ model was relatively abstract and offered insufficient guidance for the creation of a systematic process. Additionally, he overlooked certain basic phases of the design process. such as design development and production drawings phase.

Mendler and Odell (2005) formulated ten steps for a sustainable integrated design process. These steps illustrated the process as a linear system, which is incompatible with a SDP that goes through many loops and concurrent tasks.

Some literature utilized BIM concept in a design process. Al-Helal (2009) developed a flowchart model for applying BIM tools in the design process of local architecture and engineering (AE) practice in K.S.A. Similarly, Wu and Issa (2013) developed an integrated green BIM flowchart. However, both studies did not cover all aspects of the SDP.

This study incorporates IDP, BIM, and a design charrette into the design process as indicated by current studies to fill the gaps that found in the current models and to generate a comprehensive systematic flowchart. That is, the logic and consequences of these three techniques are interpreted from previous work and validated by experts.

## Methodology

This study used the flowchart technique, drawing on material in the literature review to create a SDP model. The model was developed in two stages: initial and final, which are adopted from many studies such as Farias (2015), Al-Mohaimeed (2009), and Al-Sudairi (2005). The flowchart model was built by using some basic symbols as shown in Figure 1.



Figure 1. Basic symbols used in the flowchart model

**Stage I: Initial model.** The initial model was an integration of the previous work that dealt with the three selected techniques within the design process. As discussed above, there was no clear-cut model which described the process. The method of forming the initial model was done through several phases by comparing it with the previous models. That is, the detailing of the model increased by incorporating more data from the previous literature that were represented in a process model to mimic the SDP.

**Stage II: Final model.** Upon completing the initial model, it was presented to experts in the field to gain feedback and to validate the model. Four interviewees were selected according to these criteria: first, they should have sufficient knowledge about sustainability, and second, they have produced a significant body of work either through publication or experience. According to their critiques, changes and modifications were made to refine the model.

This version of the model includes a hierarchy of inputs, processes, and outputs. Feedback loops are clearly outlined and the relations between the process components especially the interaction between design team members are formed.

### The Proposed Model of the Sustainable Design Process

The proposed flowchart model of SDP is divided into six basic phases. Figure 2 shows the general view of the process in a macro model. A micro model is shown in Figures 3.1 to 3.5, which explains the steps in more detail.

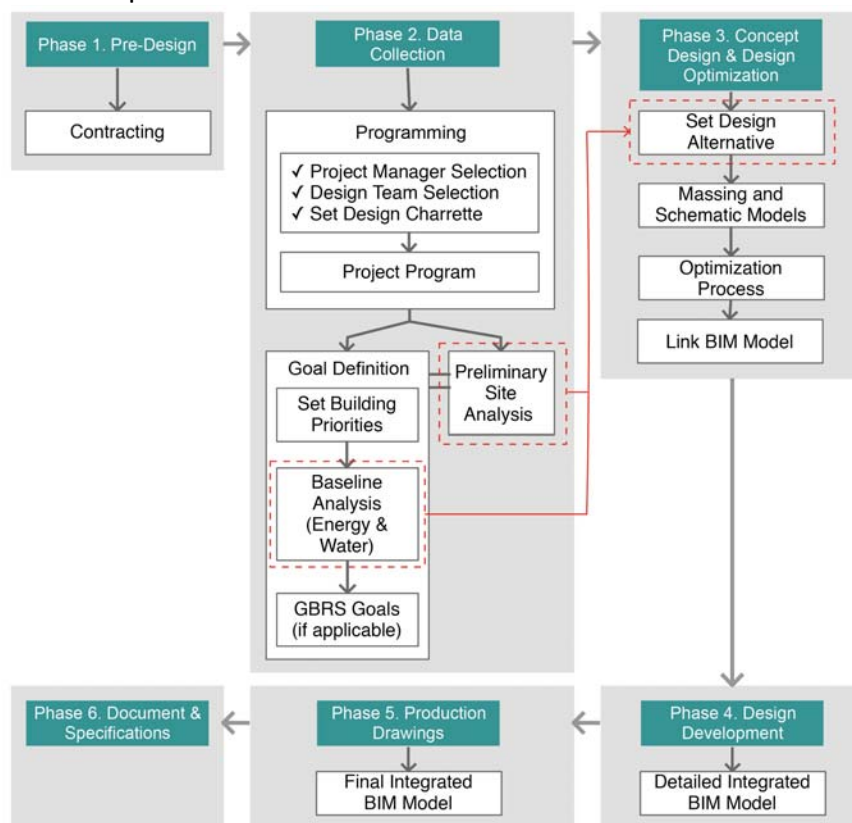


Figure 2. Macro model of SDP

#### Phase 1. Pre-Design

At this phase, several meetings are conducted to determine project scope and budget according to client needs and specifications (Al-Helal, 2010; Al-Mohaimed, 2009), as shown in Figure 3.1.

## **Phase 2. Data Collection**

This phase consists of three sub-processes: a) programming; b) goal definition; and c) preliminary site analysis. The second and the third processes are concurrent processes.

- a. **Programming.** A selection of the entire team is placed early at this phase (Mendler et al., 2005). The project manager should be qualified as a green building consultant, and it is recommended to carry LEED accredited professional license (Robichaud and Anantatmula, 2010). The design team is assembled and interviewed by the project manager (Robichaud and Anantatmula, 2010; Mendler et al., 2005) where members are acquainted to energy modelling tools and committed to sustainable design. In certain cases, an energy modelling specialist is hired to complement design team members (Mendler et al., 2005).

Moreover, the design charrette members are selected to maintain integrated team collaboration from various technical disciplines. The charrette members must include all key external stakeholders. It consists of the architecture/engineering team and their specialists representing planning, architecture, civil engineering, landscape architecture, cost consultant, MEP engineering, interior design, and the other community representatives and surrounding property owners. In some cases, it's worth to provide an additional external expertise to be involved in the charrette sessions (Kibert, 2016; Robichaud and Anantatmula, 2010; Mendler et al., 2005; Knox et al., 2013).

Subsequently, the BIM manager is assigned, and a BIM execution plan is issued. The purpose of the execution plan is to provide a framework for the client, architects, and engineers. It defines the responsibilities of parties, the details and scope of information to be shared and the suitable computer package to be used (Al-Helal, 2010).

- b. **Goal Definition.** The responsibilities of determined sustainability goals of the project are directly linked with team participants. The outcomes of expected sustainable building project are influenced by the client's commitment based on the allowed time and budget, capabilities and skills of the project team and other related factors (Wu and Issa, 2013). In this sub-phase, the client and design team should set the building priorities. For instance, the water consumption is so important in some regions, for those, the design team usually put this matter as priority into their consideration when making a decision. After setting the priorities, the design team is engaged in a discussion of sustainable issues, cost target and schedule impacts. Accordingly, the baseline analysis of water and energy must be developed at this stage.

Cost-effectiveness measures should be considered along with the LCC. Following this, the design team should check if the energy and water cost meet the initial budget, otherwise the baseline analysis should be started over. There must be a system to maintain the cost savings of energy and water over time. Therefore, the Measurement and Verification (M&V) plan have to be established in this phase (Mendler et al., 2005).

The first Value Engineering study (VE) is applied at this point to identify project priorities, objectives, requirements, design criteria and so on (Mahadik and Mahadik, 2014). Following this, a session is held with all team members to set broad goals and choose measurable outcomes, such as a LEED rating system (Farias, 2013; Kibert, 2016; Robichaud and Anantatmula, 2010). The client will seek a Green Building Rating Systems (GBRS) certification, and the target level of certification should be selected (Kibert, 2016). The next step is to designate the party responsible of accreditation. In BREEAM rating system, an external third-party is required to certify the building, however under the LEED

system, a LEED Accredited Profession (LEED AP) can be provided internally as a member of the design team (Farias, 2013).

- c. Preliminary Site Analysis. Several site issues are analyzed to identify the environmental opportunities and constraints. Figure 3.1 depicts the flow of site analysis activities. After identifying all constraints and opportunities, the planners, engineers, and landscape architects collaborate to document these findings with site analysis drawings (Mendler et al., 2005). Later, the analysis team presents all site analysis drawings in the charrette feedback session to encourage criticism from all of the team charrette members like local government planners and other regulatory agencies.

### ***Phase 3. Conceptual Design and Design Optimization***

Referring to the preliminary site analysis, the design concept should incorporate sustainable strategies, considering the site and regional ecosystem. Preliminary drawings will show major architectural spaces and masses in context (Al-Helal, 2010).

Based on the baseline analysis, some design alternatives are proposed, tested and evaluated using simulation packages. In this phase, the provision of BIM is strongly recommended for better communication within the multidisciplinary team (Farias, 2015).

During this phase, a design team meeting is set to discuss the work progress. Several layouts are produced concurrently using BIM for coordination, which are schematic structural, mechanical and plumbing layouts. These plans are produced by consultant engineers while the architectural model is being refined and detailed (Al-Helal, 2010).

The optimization system is implemented in this phase. It is applied to five aspects of the project, which are energy, water efficiency, materials and resources, site impacts, and indoor environmental quality (Mendler et al., 2005). The optimization process goes in an iterative loop where all design team works together to identify sustainable solutions (Farias, 2015).

The next steps describe the process of energy optimization to reduce overall energy consumption (Mendler et al., 2005).

- a. Gather information. The design team starts by collecting programmatic information, which are space use, population, hours of occupancy, expected equipment, and other related information. Situational information such as climate data, site characteristics, energy code requirements, and utility rate structures are also collected.
- b. Create a Base Case Energy Model. According to the information gathering, the assigned design team creates a base case energy model by using dynamic energy modelling software package. The base case model has to produce a solution that is minimally compliant with the energy code regulations. In this stage, several assumptions within the information program are made due to the design is not fully developed yet.
- c. Characterize Energy Use and Energy Cost. Simple pie charts are generated based on the base case of energy model. After that, a set of eliminations load models are developed. In this stage, chosen components are turned off one by one, to measure the impact of each factor on overall energy performance. Once this is done, the complex interaction between energy model components can be observed in relation to the energy improvement targets.
- d. Develop Alternative Design Solutions. Referring to the previous step, the design team could identify the strategies that reduce energy loads for all components of the project. Then, using energy simulation package is performed to evaluate different solutions and



compare the results with the energy base case model. Afterwards, the cost and benefits of these strategies are analysed to choose the optimum options.

The second VE study is implemented at this point, with emphasis on generating the detailed proposal for systems, producing the optimum technical and economic solution (Mahadik and Mahadik, 2014).

After that, the charrette meeting is assembled again working in short feedback loops. Following this, the LEED AP or third-party track and document the progress to meet the GBRS prerequisites and credits. Monitoring of the design progress with periodic updates of the energy model is vital to ensure that the energy budget is maintained. The energy model is modified if necessary to meet the energy budget.

After the optimization process of the five aspects is done, the alternative solutions should be linked together in one system. Then, the evaluation of the whole building systems is conducted to make sure that all strategies are working together without any conflicts. Next, a refined 3D BIM model is established based on the sustainability goals of the project (Mendler et al., 2005; Al-Helal, 2010). This process generates the final envelope design (Farias, 2013).

Following this, a linked 3D BIM model is created to refine architectural, schematic structural, mechanical, and plumbing outcomes. These BIM models are linked to perform discrepancies detection checks and changes are made if there is any discrepancy to create an integrated BIM model (Al-Helal, 2010). The integrated BIM model is presented to the charrette to get their comments. Figure 3.3 shows the flow of this phase activities.

At this point, contingent upon the client's approval, the 2D architectural drawings are generated and presented to local authorities for approval (Al-Helal, 2010).

#### ***Phase 4. Design Development***

As demonstrated in Figure 3.4, this phase starts with a meeting between the design team members to ensure that they are all up to date with the work progress, and can take into consideration the sustainability goals, and the client requirements. The design team continues development and detailing of building information models in parallel with the detailing of the five analysis aspects described above. Parametric links are maintained within the BIM models to enable automatic generation 2D graphic details (Al-Helal, 2010).

After the BIM model is integrated, another charrette feedback session is conducted. Subsequently, the LEED AP or third-party monitor will take care of the process to meet the GBRS prerequisites and credits. The BIM manager conducts a test for discrepancies detection to incorporate changes where required. Closing this phase, the client reviews the new BIM model on a form of 2D drawings (Al-Helal, 2010).

#### ***Phase 5. Production Drawings***

In this phase, all 3D BIM outcomes are finalized in parallel. The finalization process includes providing attributes for the parametric objects, e.g. specifications and cost per unit in preparation for generating bills of quantities and specifications for next phase.

The BIM outcomes are incorporated into one integrated model, and the design charrette is involved through a feedback session. Then, a final discrepancies detection test is performed for the final review. 2D drawings (plans, elevations, sections, and working drawings) are then finalized. By the end of this phase, the presentation and preparation of finalized drawings is completed (Al-Helal, 2010). Figure 3.4 demonstrates the process in more details.

## Phase 6. Integrated Documentation and Specifications

In the closeout phase, the final package from the BIM model will be generated, and it is formatted for a building permit. A bill of quantities and specifications are presented in their final form (Al-Helal, 2010), as shown in Figure 3.5.

During this phase, the design team with a LEED AP or a third-party are required to review and document the progress towards earning a GBRs. Moreover, the design team has to review and document the progress of applying sustainability design goals through the design process and document them in the contract specifications. Additionally, the design team have to produce new specification sections, which are addressing sustainability requirements (Mendler et al., 2005).

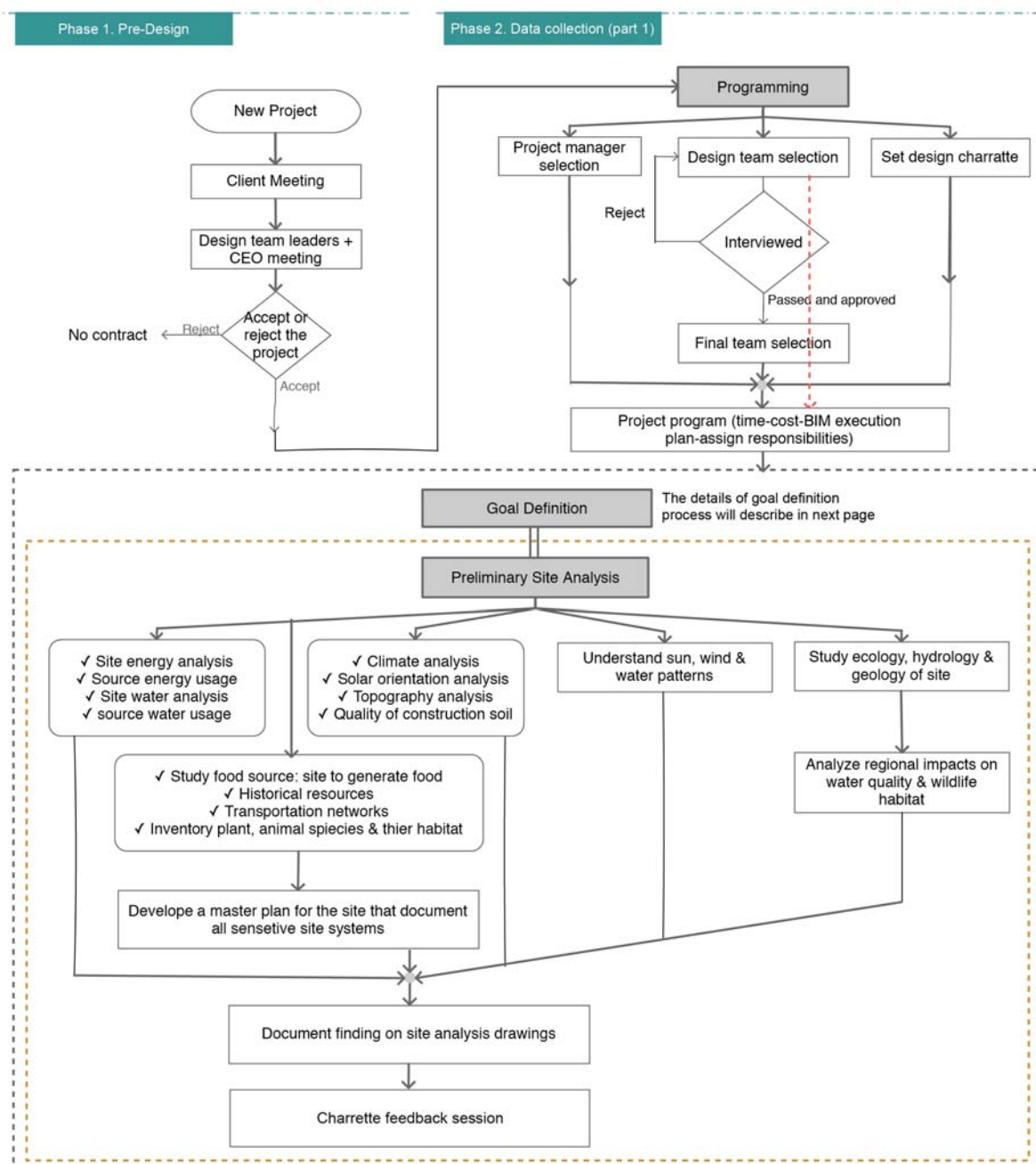


Figure 3.1. The proposed micro model of sustainable design process (phase 1 and phase 2-1)

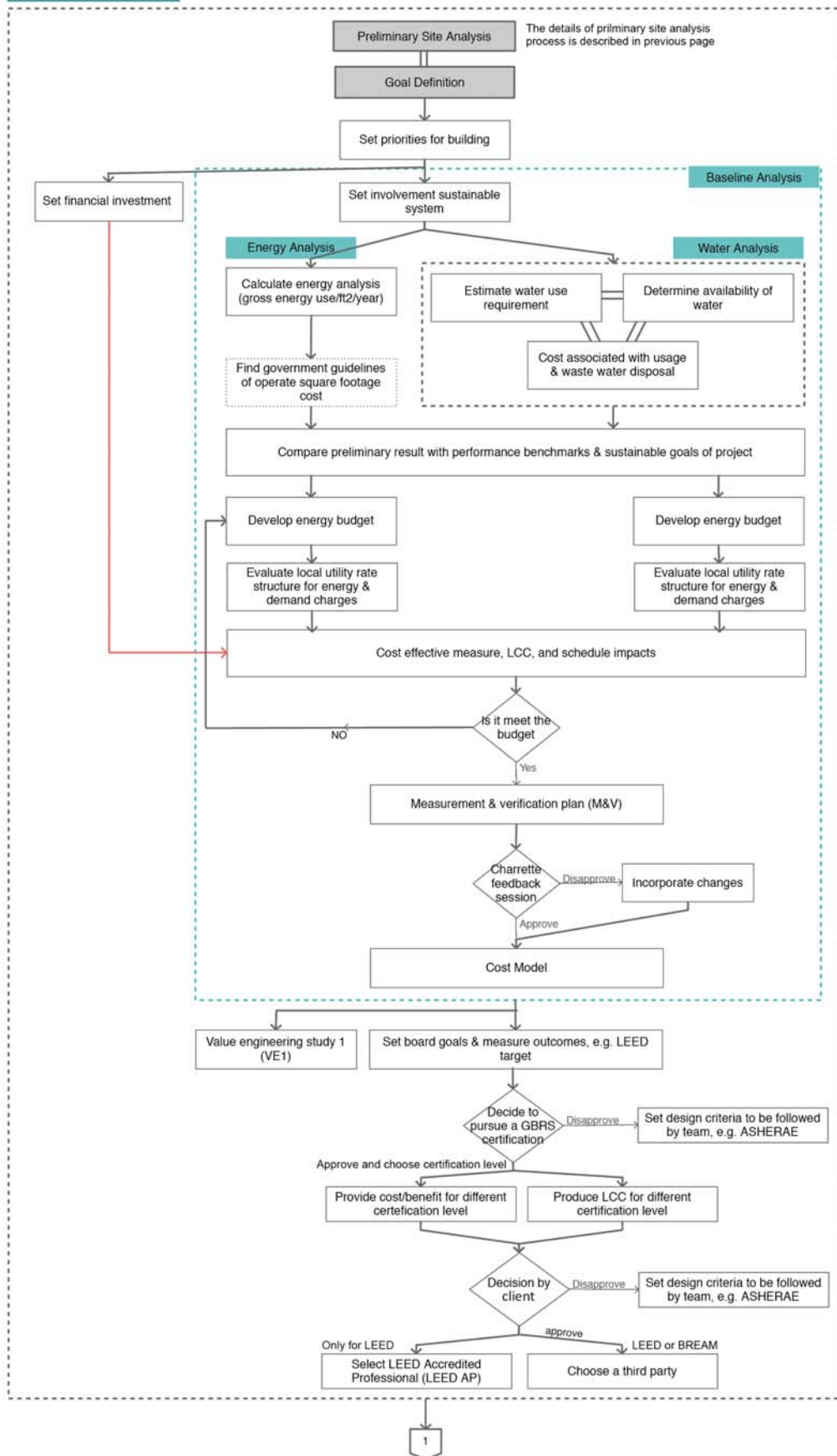


Figure 3.2. The proposed micro model of sustainable design process (phase 2-2)

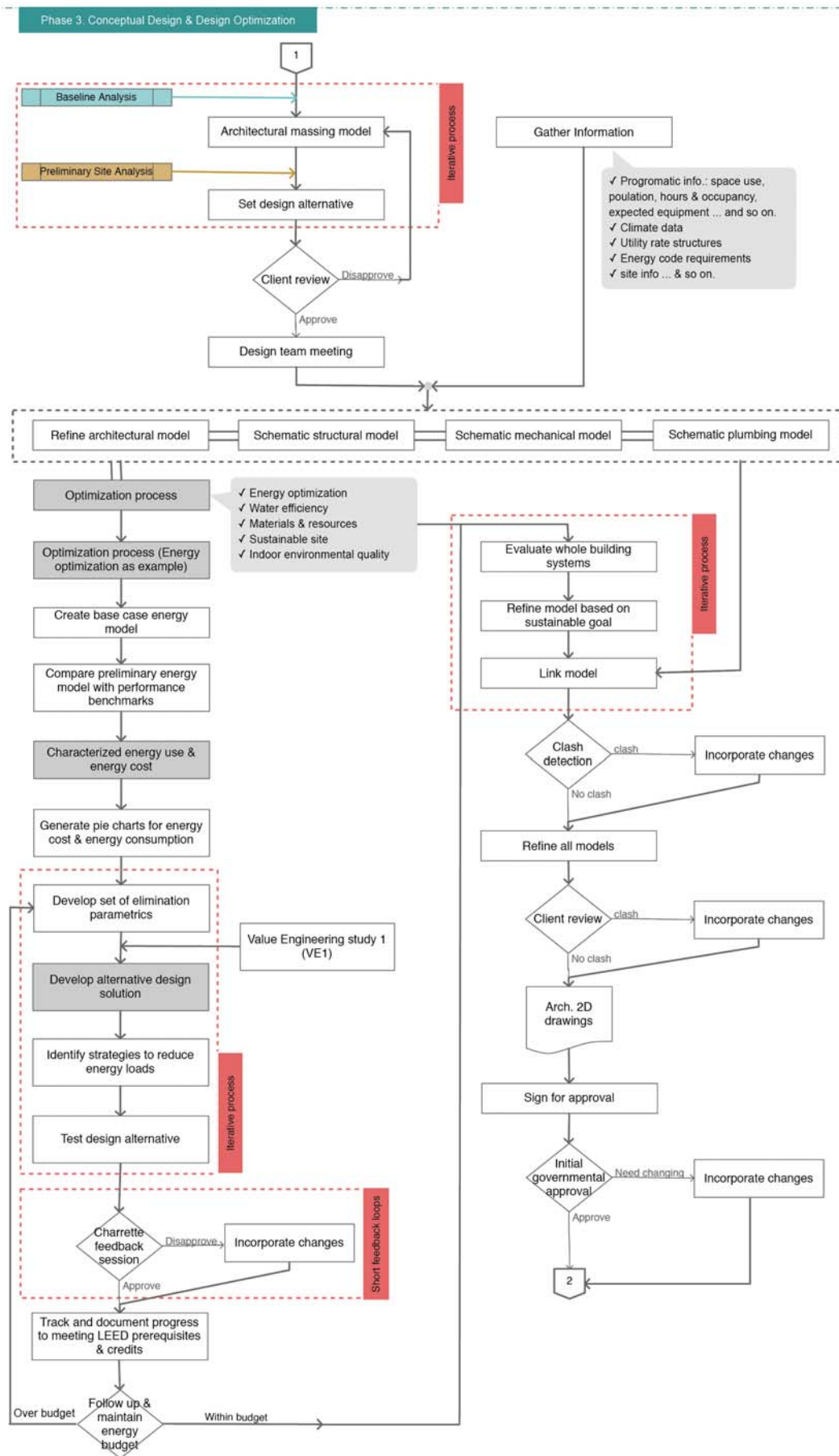


Figure 3.3. The proposed micro model of sustainable design process (phase 3)

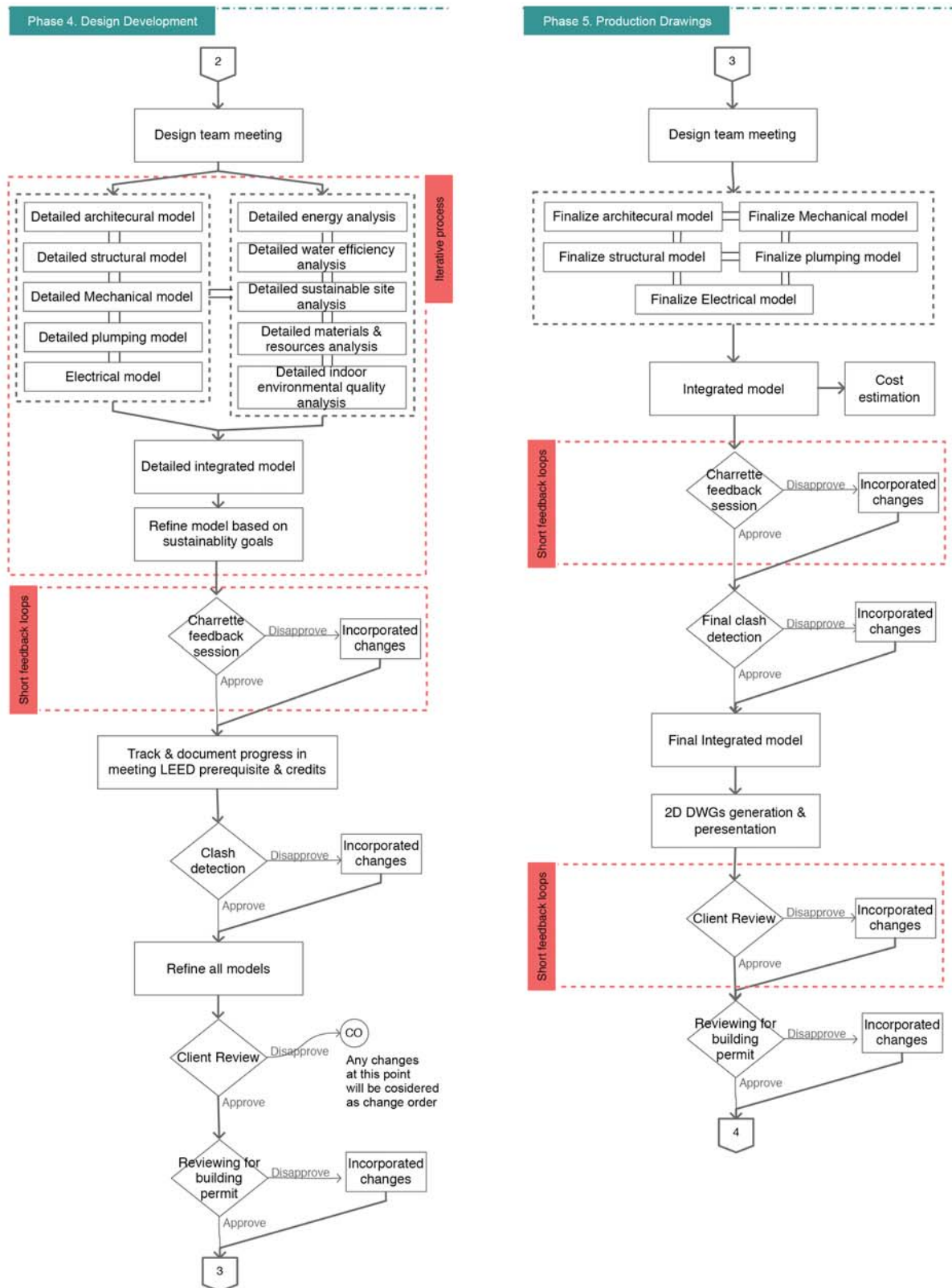


Figure 3.4. The proposed micro model of sustainable design process (phase 4 and phase 5)



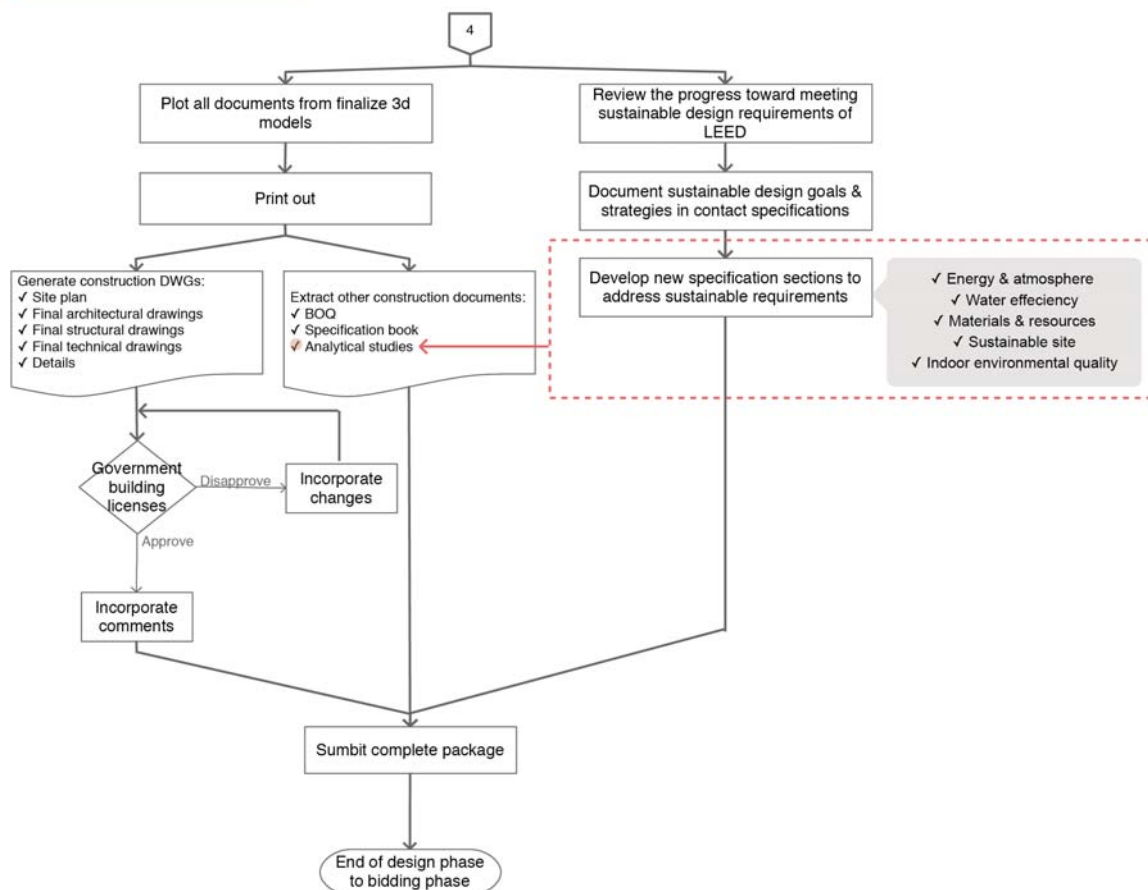


Figure 3.5. The proposed micro model of sustainable design process (phase 6)

Going through the proposed SDP model, one may notice the following:

- The SDP is a quite sophisticated system, due to the nature of the process which involves multiple activities and decisions as well as the necessary of multidisciplinary team collaboration.
- The selection and cooperation of the multidisciplinary team are very important to conduct the process with minimal conflicts and to ensure the integrity of the building systems.
- Some tasks are concurrent, as opposed to the previous models presented by other studies.
- It contains many iterative processes, where links to some steps are going back and forth. The process shows the real dynamics of the SDP to ensure that the sustainability goals of the project are met.
- The effect of design charrette is very significant because of the provision of feedback from local government planners and other regulatory agencies in different phases of the design process. Therefore, meeting community and government requirements will be highly improved.

## Conclusion

This study proposes a means for integrating sustainability into the design process through a flowchart model. Three techniques are used to develop the model, which are BIM, integrated design process, and repeated design charrettes. Applying these techniques adds value to each

phase of the design process. The model represents a holistic and systematic approach that leads to an interrelation of different subsystems facilitating improved communication and minimizing conflict and discrepancy.

It is clear that the proposed model is complex. Therefore, the next stage of research could be the use of computer simulations to further study the potential, limitations, requirements, and opportunities presented by the SDP model.

## References

Al-Sudairi, A. A. (2005) Identifying improvement opportunities to maintenance programs through flowchart ping, *Emirates Journal for Engineering Research, UAE*, 10(2), pp. 69-80.

Al-Helal, A. (2010). Improving the Architectural Design Process in Saudi Arabia-Utilizing BIM Tools. University of Dammam.

Al-Mohaimeed, E. (2009) Documenting the Architectural Design Process in Saudi Arabia, Identifying and Classifying Barriers, and improving the Design Process through Object Oriented Simulation. Master, King Fisal University, Dammam.

Farias, F. (2015) A Standard Design Process for Sustainable Design, *Procedia Computer Science*, 52, pp. 746-753.

Farias, F. (2013) Contemporary strategies for sustainable design. DOCTOR OF PHILOSOPHY, Texas A&M University, Texas.

Horman, M., Riley, D., Pulaski, M. and Leyenberger, C. (2004) Lean and green: Integrating sustainability and lean construction. CIB World Building Congress: International Council for Research and Innovation in Building and Construction (CIB) Rotterdam, The Netherlands, 2-7.

Häkkinen, T. and Belloni, K. (2011) Barriers and drivers for sustainable building, *Building Research & Information*, 39(3), pp. 239-255.

Kibert, C. J. (2016) Sustainable construction: green building design and delivery. John Wiley & Sons.

Knox, M. W., Clevenger, C. M., Dunbar, B. H. and Leigh, K. E. (2013) Impact of charrettes and their characteristics on achieved LEED certification, *Journal of Architectural Engineering*, 20(3), pp. 04013012.

Mahadik, U. A. and Mahadik, A. B. Value Engineering Tool for Sustainability in Construction Projects. Sustainable Innovative Techniques in Architecture, Civil and Environmental Engineering, New Delhi: EXCELLENT PUBLISHING HOUSE, 381-378.

Mendler, S., Odell, W. and Lazarus, M. A. (2005) The HOK guidebook to sustainable design. 2nd edition (2005) edn.: John Wiley & Sons.

Othman, A. and Nadim, W. Towards Establishing an International Sustainability Index for the Construction Industry: A Literature Review. Proceedings of the First International Conference on Sustainability and the Future, the British University In Egypt, Cairo, 23-25.

Robichaud, L. B. and Anantatmula, V. S. (2010) Greening project management practices for sustainable construction, *Journal of Management in Engineering*, 27(1), pp. 48-57.

Wu, W. and Issa, R. Integrated flowchart ping for bim implemenation in green building project delivery. Proceedings of the 13th International Conference on Construction Application of Virtual Reality, London, 30-31.

# DynamoPlus: Synchronizing Data Exchange between Dynamo and EnergyPlus

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**Abstract:** Over the past decade, there have been huge advances in both the field of visual programming and energy modelling. Significant efforts have been made to synchronize the geometric exchange of a full building information model (BIM) into energy modelling programs in the form of parametric inputs. However, limited attention was accorded to considering building properties as key inputs to energy simulation data. Issues of standardization and synchronization of simulation data exchange are critical to designers in their modelling workflow. As such, the lack of such an exchange increases the risk of errors causing thereby discrepancies in simulation results. Therefore, this paper presents a conceptual model that couples a visual program, Dynamo-BIM, with an energy simulation engine, EnergyPlus, to achieve two main objectives: (1) synchronizing the data exchange between two spatially distributed models without the need of any interface, and (2) illustrating the effect of building fenestration surfaces on energy consumption. A hypothetical case study example of an office building was used to illustrate how the proposed model synchronizes data and transfers visual representations as input data files for EnergyPlus. The model tests the effect of energy intervention scenarios, namely, the impact of internal and external shading devices on the building's energy consumption. Findings of this study shed light on the importance of matching and quantifying the main elements used as inputs to energy modelling programs in order to reduce discrepancies in simulation results.

**Keywords:** Energy Modelling, Building Simulation, EnergyPlus, Dynamo

## Background

### *BIM for BEM*

As early as the 1960's, building energy modelling (BEM) has been playing a significant role in designing energy efficient envelopes, selecting Heating Ventilation and Air Conditioning (HVAC) systems, developing building energy codes and standards, and defining/implementing building energy rating programs (Janda and Busch, 1994, Crawley et al., 2001, Gowri, 2004). On a parallel scheme, the digital revolution came forcefully into the Architecture, Engineering and Construction (AEC) industry changing the way architecture was designed, documented, visualized, and built. This new way of constructing and implementing architecture using parametric 3D came to be known as Building Information Modelling (Bianchini et al., 2017).

Over the past decade, practitioners and scholars have showed a growing interest in the fields of energy and information modelling (Oh et al., 2011, O'Donnell et al., 2013). Their endeavour has shifted from providing rules for a "Green Design" towards achieving a "Better Design". Environmental awareness and the growing demand for energy-efficient building is still an important topic but it is no more evocative as it used to be. The credibility of many of the energy certification schemes has been questioned and studies have showed gaps in accurately predicting the energy performance of a building based on a given rating system (Roderick et al., 2009). For instance, according to Pérez-Lombard et al. (2009), one of the main issues facing the proper implementation of a certification scheme is the development of an energy performance calculation tool. Maile et al. (2007) explained that

inconsistencies in energy modelling values are mainly due to: (1) assumption regarding input information, and (2) the dynamic occupant usage of buildings. Zhu et al. (2013) compared the simulation results of three energy modelling programs using ASHRAE standard 140 tests. The authors concluded that easy-to-use interfaces do not make energy analysis available to everyone. Realizing the limitations of the simulation engine as well as data input is crucial for generating realistic and reliable results. As such, to address the aforementioned problems, BIM has come into play and has been utilized to leverage building information that exists in the architectural model. According to Hyun et al. (2015), BIM can play a key role in improving the consistency of construction information related to building energy analysis. Additionally, by using BIM, the process of creating an energy model can be easily automated. Consequently, geometry and other assumptions detailed in the architectural model remain consistent and are not subject to interpretation or improper simplification. Furthermore, Welle et al. (2011) showed that a BIM-based energy model is capable of significantly reducing simulation times while improving consistency over conventional methods. However, while the potential benefits of BIM tools in addressing issues related to energy modelling have been recognized, interoperability between these two spatially distributed models remains one of the biggest challenges (Prada-Hernández et al., 2015).

### ***Interoperability: IFC, gbXML, and Visual Programming***

Conventionally, extracting input data from BIM for energy modelling has been relying on two main methods; namely the Industry Foundation Class (IFC) and the Green Building XML (gbXML) (Miller et al., 2014). Both of these schemes are supported by BIM software packages such as Revit and ArchiCad along with energy simulation tools such as Green Building Studio, Hourly Analysis Program (HAP), Ecotect, and eQUEST (Maile et al., 2007). However, BIM-based information transfer is not seamless and users of these methods have little control over how data files are created or loaded (Kumar, 2008, Miller et al., 2014). As reported by Noack et al. (2017) the conversion process is far away from becoming a single click solution and it is primarily hampered by inconsistent geometric definitions. While some research efforts tried to tweak the inconsistencies of the previously described schemes, others went to propose new conversion methods. Bazjanac (2008) proposed an IFC BIM-based methodology to semi-automate the energy simulation process. However, this data extraction only covered the geometric aspect and a lot of simulation parameters had to be input manually. Similarly, Oh et al. (2011) developed a gbXML-IDF convertor to exchange BIM data with EnergyPlus but user intervention was still required by analysis experts to modify unstructured data. Kim and Yu (2016) used an IFC schema to import data, and a default library database to systematically match the specific information needed. However, the accuracy of the proposed system depended highly on the library database. Welle et al. (2011) introduced ThermoOpt; a methodology that uses IFC scheme to feed data into an optimization environment by using an IFC middleware and an analysis application user interface. Dimitriou et al. (2016) focused on the conversion process from gbXML into an "idf" EnergyPlus input file. Once more, this methodology required the use of an editing tool to add any missing information to the exported data. Overall, most of these studies addressed the process of data input using specific BIM-based energy simulation interfaces, as described by Maile et al. (2007), while making use of conventional interoperability schemes such as IFC and gbXML.

On the other hand, the Visual Programming Language (VPL) is starting to gain momentum in the world of BIM and parametric modelling. VPL allows novice users in programming to create computer programs by building visual relationships between elements within a user friendly interface (Boeykens and Neuckermans, 2009). Examples of visual programming tools for architectural designs include Grasshopper for Rhino-3D and Dynamo for Autodesk Revit, and where Grasshopper doesn't work directly with BIM, Dynamo includes parametric geometries and works in parallel with Revit. Research has already started to exploit the potential of VPL in the AEC industry. For instance, Roudsari et al. (2013) used Ladybug, a plugin for Grasshopper, to create interactive graphics for weather data visualization. Similarly, within the same platform of Rhino/Grasshopper, Touloupaki and Theodosiou (2017) proposed a new design workflow methodology that uses another plugin, HoneyBee, to connect the parametric geometry with an energy simulation engine such as EnergyPlus. Likewise, Kensek (2015) showed that one can update and extract project parameters directly within BIM by using Dynamo as a VPL. The feasibility of this workflow was contrasted against the conventional data transfer models using neutral file formats such as IFC and gbXML. Asl et al. (2015) proposed a framework that automatically generates, evaluates and optimizes multiple design options. The framework utilizes Application Programming Interface (API) to set up a visual programming environment, a cloud-based simulation engine (Green Building Studio), and an optimization algorithm. Preidel and Borrmann (2016) used VPL to automate the code compliance checking process for different applications in the AEC industry. Seghier et al. (2017) developed a BIM-VPL tool for building envelope design and analysis. The data was extracted from BIM and managed using Revit, Excel and Dynamo.

However, none of the aforementioned research efforts has targeted coupling BIM with BEM. Therefore, in order to address the limitations of the literature, this paper presents a novel graphical visual programming interface, DynamoPlus, that aims at automating the geometry translation process from BIM to BEM, in other words inducing BIM-BEM interoperability. It also creates a methodology to assess and analyze different design alternatives affecting energy consumption and thermal behavior of a building. The final stage includes studying thermal design loads and as such devising twelve different simulation scenarios in DynamoPlus and comparing the results against those of two other tools, namely HAP and Elite Commercial HVAC Loads (Elite-Chvac).

## Methodology

The development of an all-inclusive energy model begins by creating a generic framework that couples BIM-VPL functionalities with the required data input of an energy simulation engine. The proposed model enables designers to explore design alternatives by testing their impact on the overall energy performance of a building. This is achieved in this study through the development of DynamoPlus that couples an energy simulation engine, EnergyPlus with a BIM-based tool, Revit, through the use of a VPL, Dynamo (Figure 1). At the heart of this synergy, Dynamo forges a bi-directional link that can import and export data according to the requirements of the simulation engine and/or the design preferences of the user. To that end, two major mechanisms are established: (1) Evaluating the simulation engine to determine the required input data and attributes, and (2) Screening available



functionalities in Revit in order to develop a suitable VPL platform that extracts/creates the required data then writes it as an EnergyPlus input data file (i.e. IDF).

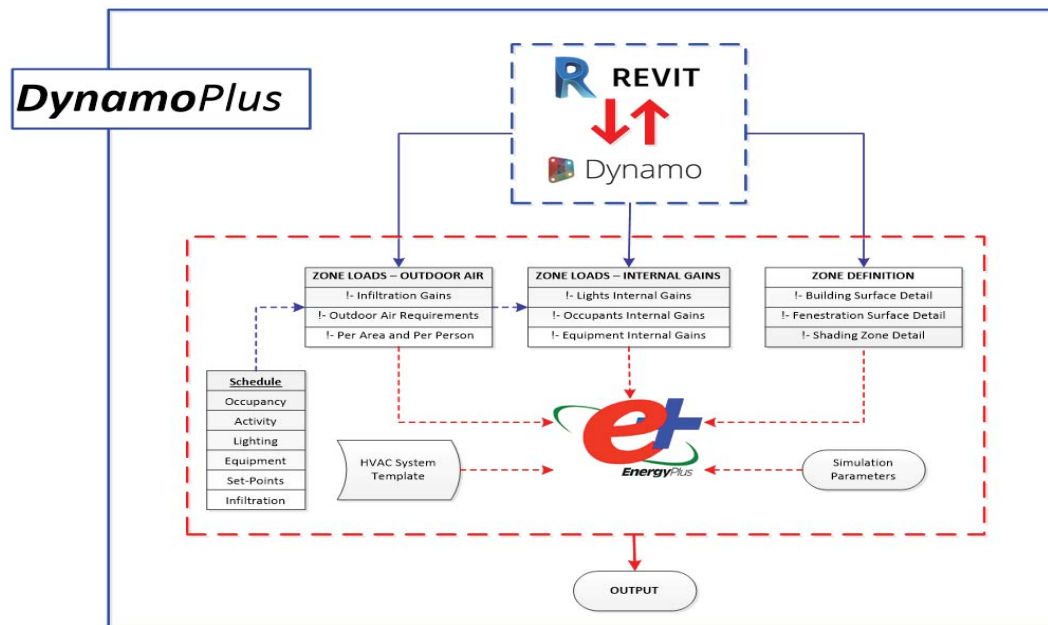


Figure 1. DynamoPlus model

### EnergyPlus Module

EnergyPlus is a free tool developed by the Department of Energy (DOE) for energy simulation, load calculation and building performance. It is currently considered as one of the most accurate simulation engines (Crawley et al., 2008). However, it is based on the input from text files, which increases the effort needed by the user to define all necessary input data compared to engines with graphical user interfaces. Since any simulation result is as accurate as the input data, the evaluation process uses a bottom-up approach to analyze and understand the different components needed for simulation. EnergyPlus includes a set of object-based descriptions of the building and its system. The basic syntax is "Object, data, ..., data;" . Objects are predefined to represent a building component such as a building "surface". The object is then followed by a list of data values that terminates with a semicolon. In this model, three major objects were created for EnergyPlus: Zone Definition, Zone Loads-Internal Gains, and Zone Loads-Outdoor Air. According to this architecture, six generic "IDF" files were created as the basis for any energy simulation using EnergyPlus. More specifically, the six files include: "IDF-1" Simulation Parameters, "IDF-2" Schedules, "IDF-3" Construction set, "IDF-4" Zone Definitions, "IDF-5" Zone Loads, and "IDF-6" HVAC system.

As discussed earlier, Dynamo is handling the automatic conversion of BIM data into "IDF-4" & "IDF-5". The logic behind the conversion process is visually presented in Figure 2. The process starts by setting the "Thermal Zones" then automatically the "Surface" and "Sub-Surfaces" objects are defined. Internal and external loads are later calculated based on default construction and schedule sets described by the user or an energy standard such as ASHRAE's 90.1.

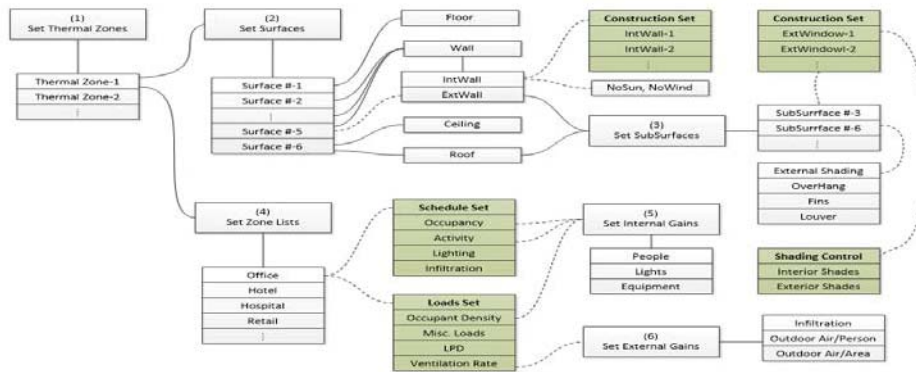


Figure 2. EnergyPlus Zone Definition and Zone Loads workflow

As with most energy modelling approaches, there are default assumptions that need to be set prior to simulation. Among these are the construction set and the activity schedules; highlighted in green in Figure 2. The construction set is part of a Revit template which the designer uses to construct “surfaces” and “sub-surfaces”. It is worth noting that the thermal mass is not considered since insulation is used on external surfaces. The HVAC system is also part of a default template in EnergyPlus under the object “IdealLoadsAirSystem”. The system is modelled as an ideal VAV terminal that supplies cooling or heating air to a zone in sufficient quantity to meet the zone load (EnergyPlus, 2017).

### Dynamo-Revit Module

In a parametric design, a designer starts by defining a family instead of a building element like a wall, door, etc. Each family has a collection of a fixed parametric geometry such as width or height. VPL helps in setting relations and rules to control the parameters by which element instances are created. Hence, Dynamo - a free visual programming tool - generates geometries and manipulates models by coupling nodes which are programmed to execute a specific task. Figures 3 to 5 illustrate a typical workflow in Dynamo, in particular the one used to generate “IDF-4” Zone definitions. The rest of the IDF files are generated in a similar manner. The blocks are referred to as nodes and they are connected with wires forming a visual program called a graph (Dynamo, 2017).

The first step in building a Dynamo-Revit framework consists of starting with a Revit Model and selecting or generating project parameters in case not present in the Revit model. In the case of this workflow, it is assumed that none of the required parameters are loaded into BIM- which is hardly the case. Figure 3 depicts, for the case of a floor surface, how all the elements needed to generate an object are created in EnergyPlus. The reason for this setup is to show the bi-directional link between Revit and Dynamo. In a real case scenario, the parameters are directly extracted in the same manner they are listed under the BIM-based Revit model. The next step works on extracting the geometric parameters of the surface and any sub-surface included within. In Figure 4, the first node reads the subject element as a floor. The second node starts by coding all the curves or lines while the third indexes the points and lists them in a syntax readable by EnergyPlus. In the final step of this workflow, the values of the parameters listed in Figure 3 are extracted. A new list is then created to combine parameter values and floor vertices under the object name: “BuildingSurface:Detailed”. A semicolon is added after the last set of vertices to form the basic syntax of “Object, data, ..., data;”. Once this list is completed, the six “IDF” files together with a weather file are used in EnergyPlus to run the energy analysis.

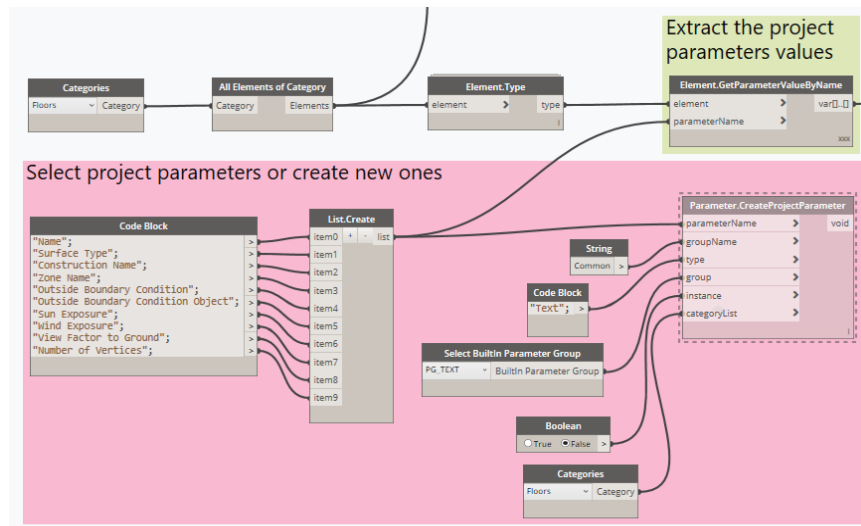


Figure 3. Dynamo graph for selecting and generating project parameters

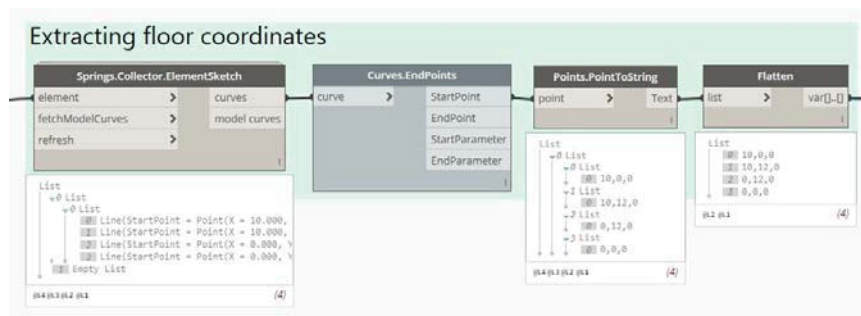


Figure 4. Dynamo graph for extracting floor vertices

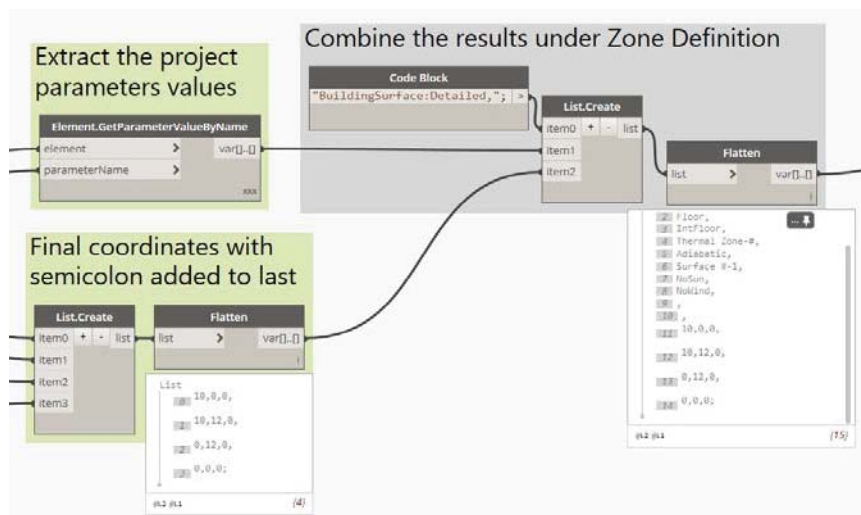


Figure 5. Combining project parameters and vertices under assigned object

### DynamoPlus Testing Flowchart

Figure 6 presents a flowchart for testing DynamoPlus. The process starts by building two models; one that represents the existing building and the other is a base model which adopts the prescriptive building envelope requirements set by ASHRAE Standard 90.1-2010 or the Thermal Standards for building in Lebanon (TSBL)-2010. The base models are used as

a source for calculating the baseline energy performance. If the energy consumption of the building is less than or equal to the calculated baseline, the process ends. However, if values exceed the maximum allowed, then the user starts varying different parameters until the required level of energy consumption is reached. Ideally, this latter stage will be automated in a future work (i.e. green box in Figure 6).

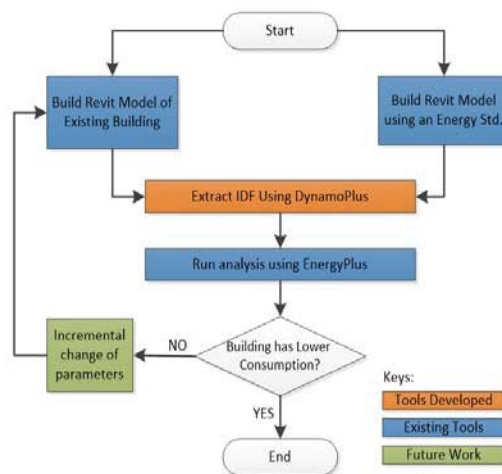


Figure 6. Flowchart for testing DynamoPlus

## Results and Analysis

In this study, the validation of the DynamoPlus tool takes on two pathways: (1) Testing the whole workflow on an existing building while devising intervention scenarios at the end that would reduce energy consumption and (2) Testing DynamoPlus as a load design tool used to select HVAC systems. The building under study is an open space office located in Beirut, Lebanon. The space has a total floor area of 120m<sup>2</sup> and a height of 4m. The values for the different envelope components are based on construction documentation provided by building operators and are summarized in Table 1.

Table 1. Building envelope requirements under different standards

	Existing Building	ASHRAE 90.1-2010	TSBL 2010
Opaque Elements			
Roof (W/m <sup>2</sup> K)	0.49	0.153	0.71
Mass wall (W/m <sup>2</sup> K)	0.45	0.86	1.26
Floors (W/m <sup>2</sup> K)	0.6	0.6	NR
Fenestration Vertical			
WWR	90%	40%	40%
Assembly Max U (W/m <sup>2</sup> K)	3.04	3.07	5.8
Assembly Max SHGC	0.55	0.25	NR
Assembly Min VT/SHGC	1.2	1.1	NR

A Revit model that takes into account all the preceded parameters is illustrated in Figure 7. The glazed surface is oriented towards the North with a window to wall ratio (WWR) of 0.9 and an external shading device (overhang) with a projection factor (PF) of 0.45. Internal shades are modelled, as required by ASHRAE std. 90.1-2010, with a visible light transmittance of 0.1, a visible light reflectance of 0.4, a solar transmittance of 0.21, and a solar reflectance of 0.23.

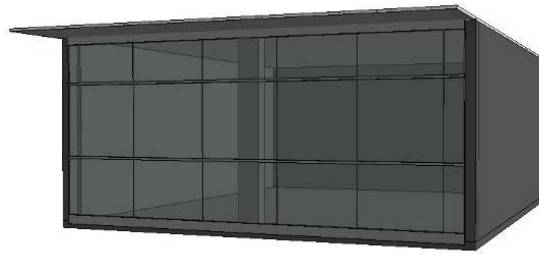


Figure 7. 3D Revit Model for existing office

In addition to the geometric parameters, simulation parameters related to occupancy and usage patterns are justified according to ASHRAE's standards on energy (90.1-2010) and ventilation (62.1-2013). Values including occupant densities, lighting power densities (LPD) are presented in Table 2. Once the Revit model is finalized, DynamoPlus generates the six "IDF" files and simulation gets then initiated in EnergyPlus.

Table 2. Zone internal and external gains prescriptive requirements

Building Type	Density (person/100m <sup>2</sup> )	Activity (W/person)	LPD (W/m <sup>2</sup> )	Ventilation Rate (L/s.m <sup>2</sup> )	Misc. Loads (W/m <sup>2</sup> )
Office	5	120	10.5	0.425	8

Based on the simulation, the annual energy consumption for the existing building is 95 Gigajoule (GJ) with 66% of this amount accounting for cooling. However, a base case is needed for comparison. A typical scenario is to have real data collected on the actual performance of the building. But since none of the required data has been logged, two base models that follow the prescriptive requirements of ASHRAE-90.1 and TSBL-2010, are constructed. Figure 8 displays the model for the base case.



Figure 8. 3D Revit Model for the base case

The geometric characteristics, with the exception of the overhang, have been kept the same, in particular the orientation, floor area, and the height. However, envelope parameters such as the WWR, thermal heat transmittance (U-factor) for opaque elements, solar heat gain coefficient (SHGC) and visible transmittance (VT) for vertical fenestration are modified as recommended in Table 1. In this case, the simulations have been performed considering the configurations prescribed by the two base models. As a result, the annual energy consumption of the base cases ASHRAE 90.1 and TSBL is 85 and 106 GJ respectively (Figure 9). Furthermore, the existing building is meeting the baseline required by the local standard but exceeding ASHRAE 90.1 baseline by 10 GJ (Figure 10).



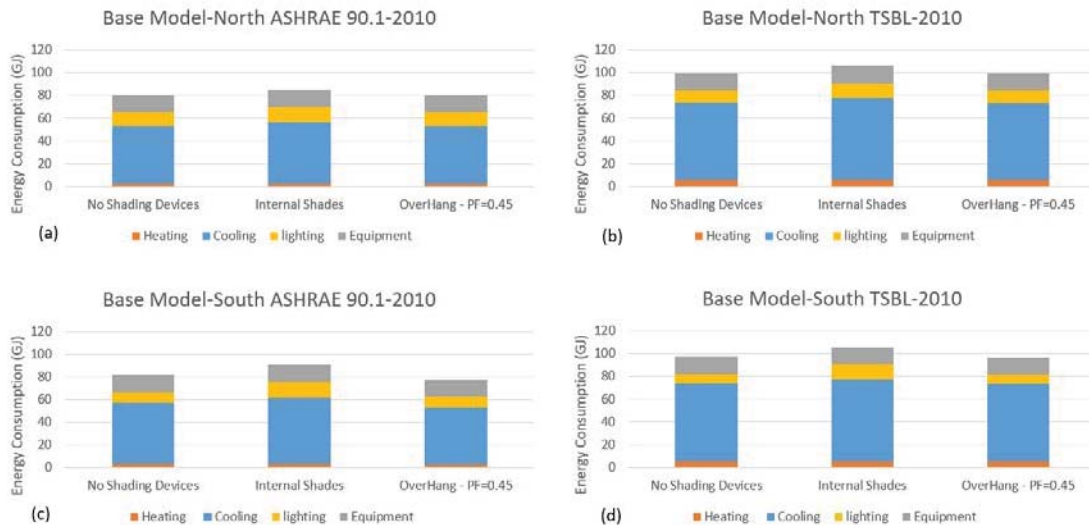


Figure 9. Energy consumption of the base models

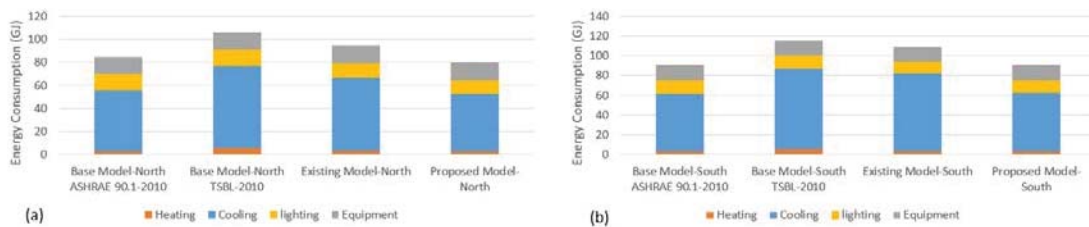


Figure 10. Comparison of energy consumption between the existing, base, and proposed models

More specifically, the impact of internal and external shading devices on the building energy consumption is analyzed. In this case, for the base model with North exposure, internal shading devices increase lighting needs by approximately 20% accompanied by a slight increase in cooling loads by about 5% (Figure 9). However, overhangs on a north exposure do not have an apparent effect on energy consumption as shown in Figure 9(a). This is due to the fact that the glazed surface is oriented towards the north. As such, the base models are rotated by 180 degrees in order to study the efficacy of using overhangs on a south exposure. The south orientation is chosen because of the sun path diagram in the northern hemisphere. Simulation results of the latter case are shown in Figures 9 (c) and (d). Internal shades are still causing an increase in the lighting and cooling needs, resulting in an overall increase of 12% in energy consumption. However, the use of an overhang hardly increases lighting needs but reduces cooling loads by up to 10% resulting in about a 7% decrease in the annual energy consumption. In a nutshell, internal shading devices increase lighting needs for both a north and a south exposure, but they are essential elements needed for privacy, thermal comfort, and visual comfort. Furthermore, although overhangs are impractical at the north exposure, they reduce cooling needs and in turn energy consumption by 7% at the south exposure. Moreover, with reference to Figures 9 (a) and (c), the north exposed model consumes 80 GJ compared to a 70 GJ for a south exposed model. This shows how an overhang can reduce the energy consumption of a building had it been oriented towards the north.

On the other hand, after performing different simulation runs and finding out that the existing building is not meeting the baseline energy requirements of ASHRAE std. 90.1, two

new models are proposed. As the previous analysis shows that shading devices are ineffective, the next steps involves varying the envelope parameters. With reference to Table 1, possible choices include: (1) reducing the U-factor of the roof or (2) selecting a glazing system with a lower SHGC. As north exposures don't receive any direct solar radiation, the choice lands on the former option. In this case, the construction documents received from the operator of the building show that 5 cm of extruded polystyrene is used for roof insulation. As such, increasing this value by an additional 5 cm can lead to a total U-value of 0.26 W/m<sup>2</sup>K. After adjusting this parameter and running the simulation, the total energy consumption was reduced to 85 GJ as shown in Figure 10 (a). A similar approach is adopted for the case with a south exposure. However, testing whether the increase of the PF to 0.65 would have any impact on energy consumption is carried out. Results show that, beyond a PF of 0.45, energy consumption decreases at a low rate, around 2%. Therefore, several incremental changes of parameters are required. For instance, by using a U-value of 0.26 for the roof and changing the glazing system to a double green low-E (e=0.1 on surface 3, U=2.89, SHGC=0.34, and TV=0.55), the total energy consumption is reduced to 90 GJ as shown in Figure 10 (b).

The first path of the validation process addressed energy consumption. The other path tests DynamoPlus as a load design tool used to select appropriate HVAC systems. In this case, results from DynamoPlus are compared against those from two other tools; namely HAP and (Elite-Chvac) which are considered popular tools among practitioners when estimating thermal loads and designing HVAC systems. At this juncture, it is worth elaborating on the confusion surrounding Load/Demand and Energy. Demand is the highest amount of power recorded for a building at a point in time and is an instantaneous quantity measured in kW. Power is the rate at which Energy is generated or consumed (i.e. measure of capacity in kWh or Joules). The higher the demand the faster the building is consuming energy. Accordingly, the peak cooling load design is used for sizing the cooling system and is calculated at an outdoor dry-bulb temperature corresponding to 1% annual cumulative frequency of occurrence in conjunction with the mean coincident outdoor wet-bulb temperature (ASHRAE, 2010). Hence, twelve different simulation scenarios are conducted separately on DynamoPlus, HAP, and Elite-Chvac and results are depicted in Figure 11. A pairwise t-test is then used to compare the validity of the simulation output. The following null hypothesis is tested: "the mean difference between paired observations is zero". Results show that there is a statistical significance between the output of different tools with p-values of 0.0014, 0.00007, and 0.0036. However, this divergence is likely not caused by discrepancies in the input parameter for the load design tool but rather by the load calculation algorithms adopted by each of these tools. More precisely, DynamoPlus or Energy Plus uses ASHRAE's preferred Heat Balanced (HB) approach whereas HAP and Elite use the Transfer Function Method (TFM) and the Cooling Load Temperature Difference (CLTD) both of which are simplified forms of HB.

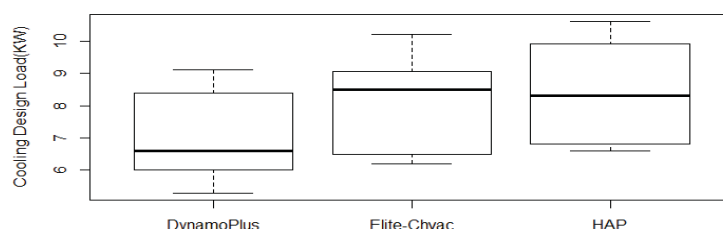


Figure 11. Comparison of 3 HVAC system load design tools

## Conclusion

This paper presents a novel BIM-BEM interface which utilizes Dynamo as a visual programming tool to extract encapsulated information from a BIM-based Revit model in order to create an input data file (IDF) for EnergyPlus. The paper also proposes a methodology to assess and analyze different design alternatives affecting energy consumption and thermal behavior of a building, in particular the use of internal and external shading devices. Results revealed that internal shading devices increase energy consumption for both a north and a south exposure, but they are essential elements needed for privacy, thermal comfort, and visual comfort. Furthermore, overhangs are impractical if used on the North side, but can reduce energy consumption by 7% when used on the South side. Thermal design loads for the existing building were also studied using 3 different tools; namely HAP, Elite, and DynamoPlus. It was concluded that the load calculation algorithms adopted by each of these tools have a major impact on the design loads and consequently the selection of an HVAC system. Future work on DynamoPlus will seek to replace the static occupancy schedule by importing the actual behavior of occupants followed by setting up a multi-objective optimization model to select the optimal HVAC system.

## Acknowledgement

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## References

- ASHRAE 2010. ANSI/ASHRAE/IES Standard 90.1-2010 Energy Standard for Buildings Except Low-Rise Residential Buildings.
- ASL, M. R., ZARRINMEHR, S., BERGIN, M. & YAN, W. 2015. BPOpt: A framework for BIM-based performance optimization. *Energy and Buildings*, 108, 401-412.
- BAZIANAC, V. 2008. IFC BIM-based methodology for semi-automated building energy performance simulation. *Lawrence Berkeley National Laboratory*.
- BIANCHINI, C., INGLESE, C., IPPOLITO, A., MAIORINO, D. & SENATORE, L. J. 2017. Building Information Modeling (BIM). *Handbook of Research on Emerging Technologies for Digital Preservation and Information Modeling*.
- BOEYKENS, S. & NEUCKERMANS, H. 2009. Visual Programming in Architecture: Should Architects be trained as programmers?
- CRAWLEY, D. B., HAND, J. W., KUMMERT, M. & GRIFFITH, B. T. 2008. Contrasting the capabilities of building energy performance simulation programs. *Building and environment*, 43, 661-673.
- CRAWLEY, D. B., LAWRIE, L. K., WINKELMANN, F. C., BUHL, W. F., HUANG, Y. J., PEDERSEN, C. O., STRAND, R. K., LIESEN, R. J., FISHER, D. E. & WITTE, M. J. 2001. EnergyPlus: creating a new-generation building energy simulation program. *Energy and buildings*, 33, 319-331.
- DIMITRIOU, V., FIRTH, S. K., HASSAN, T. M. & FOUCAL, F. 2016. BIM enabled building energy modelling: development and verification of a GBXML to IDF conversion method.
- DYNAMO. 2017. *The Dynamo Primer* [Online]. Available: [http://dynamoprimer.com/en/01\\_Introduction/1-1\\_what\\_is\\_visual\\_programming.html](http://dynamoprimer.com/en/01_Introduction/1-1_what_is_visual_programming.html) [Accessed].
- ELITE-CHVAC. 2005. *Commercial HVAC Loads* [Online]. Available: <http://www.elitesoft.com/> [Accessed].
- ENERGYPLUS. 2017. *Engineering Reference - EnergyPlus Documentation* [Online]. Available: [https://energyplus.net/sites/default/files/pdfs\\_v8.3.0/EngineeringReference.pdf](https://energyplus.net/sites/default/files/pdfs_v8.3.0/EngineeringReference.pdf) [Accessed].

- GOWRI, K. 2004. Green building rating systems: An overview. *ASHRAE journal*, 46, 56.
- HAP. 2014. *Hourly Analysis Program* [Online]. Carrier. Available: <https://www.carrier.com/commercial/en/us/software/hvac-system-design/software-downloads/> [Accessed North American Edition].
- HYUN, S., MARJANOVIC-HALBURD, L. & RASLAN, R. 2015. Investigation into informational compatibility of Building Information Modelling and Building Performance Analysis software solutions. *WIT Transactions on The Built Environment*, 149, 543-553.
- JANDA, K. B. & BUSCH, J. F. 1994. Worldwide status of energy standards for buildings. *Energy*, 19, 27-44.
- KENSEK, K. 2015. Visual programming for building information modeling: energy and shading analysis case studies. *Journal of Green Building*, 10, 28-43.
- KIM, K. & YU, J. 2016. BIM-based building energy load calculation system for designers. *KSCE Journal of Civil Engineering*, 20, 549-563.
- KUMAR, S. 2008. *Interoperability between building information models (BIM) and energy analysis programs*, University of Southern California.
- LADYBUG & HONEYBEE. Available: <http://www.grasshopper3d.com/group/ladybug> [Accessed].
- MAILE, T., FISCHER, M. & BAZJANAC, V. 2007. Building energy performance simulation tools-a life-cycle and interoperable perspective. *Center for Integrated Facility Engineering (CIFE) Working Paper*, 107, 1-49.
- MILLER, C., THOMAS, D., IRIGOYEN, S. D., HERSBERGER, C., NAGY, Z., ROSSI, D. & SCHLUETER, A. 2014. BIM-extracted EnergyPlus model calibration for retrofit analysis of a historically listed building in Switzerland. *Proceedings of SimBuild*.
- NOACK, F., KATRANUSCHKOV, P., SCHERER, R., DIMITRIOU, V., FIRTH, S., HASSAN, T., RAMOS, N., PEREIRA, P., MALÓ, P. & FERNANDO, T. Technical challenges and approaches to transfer building information models to building energy. *eWork and eBusiness in Architecture, Engineering and Construction: ECPPM 2016: Proceedings of the 11th European Conference on Product and Process Modelling (ECPPM 2016)*, Limassol, Cyprus, 7-9 September 2016, 2017. CRC Press, 355.
- O'DONNELL, J. T., MAILE, T., ROSE, C., MRAZOVIC, N., MORRISSEY, E., REGNIER, C., PARRISH, K. & BAZJANAC, V. 2013. Transforming BIM to BEM: Generation of building geometry for the NASA Ames sustainability base BIM.
- OH, S., KIM, Y.-J., PARK, C.-S. & KIM, I.-H. Process-driven BIM-based optimal design using integration of EnergyPlus, genetic algorithm, and pareto optimality. *Proceedings of the 12th IBPSA Conference*, November, 2011. 14-16.
- PÉREZ-LOMBARD, L., ORTIZ, J., GONZÁLEZ, R. & MAESTRE, I. R. 2009. A review of benchmarking, rating and labelling concepts within the framework of building energy certification schemes. *Energy and Buildings*, 41, 272-278.
- PRADA-HERNÁNDEZ, A. V., ROJAS-QUINTERO, J., VALLEJO-BORDA, J. & PONZ-TIENDA, J. 2015. Interoperability of building energy modeling (BEM) with building information modeling (BIM). *Proceedings of the SIBRAGEC ELAGEC*, 519-526.
- PREIDEL, C. & BORRMANN, A. 2016. Towards code compliance checking on the basis of a visual programming language. *Journal of Information Technology in Construction (ITcon)*, 21, 402-421.
- RODERICK, Y., MCEWAN, D., WHEATLEY, C. & ALONSO, C. Comparison of energy performance assessment between LEED, BREEAM and Green Star. *Eleventh International IBPSA Conference*, 2009. 27-30.
- ROUDSARI, M. S., PAK, M. & SMITH, A. Ladybug: a parametric environmental plugin for grasshopper to help designers create an environmentally-conscious design. *Proceedings of the 13th international IBPSA conference held in Lyon, France Aug, 2013*.
- SEGHER, T. E., LIM, Y. W., AHMAD, M. H. & SAMUEL, W. O. 2017. Building Envelope Thermal Performance Assessment Using Visual Programming and BIM, based on ETTV requirement of Green Mark and GreenRE. *International Journal of Built Environment and Sustainability*, 4.
- TOULOUPAKI, E. & THEODOSIOU, T. 2017. Optimization of building form to minimize energy consumption through parametric modelling. *Procedia Environmental Sciences*, 38, 509-514.
- WELLE, B., HAYMAKER, J. & ROGERS, Z. ThermalOpt: A methodology for automated BIM-based multidisciplinary thermal simulation for use in optimization environments. *Building Simulation*, 2011. Springer, 293-313.
- ZHU, D., HONG, T., YAN, D. & WANG, C. A detailed loads comparison of three building energy modeling programs: EnergyPlus, DeST and DOE-2.1 E. *Building Simulation*, 2013. Springer, 323-335.

# Analogue and Advanced Digital Simulation to Assist Spatial and Daylighting Design in the Educational Context

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**Abstract:** Architecture as a professional degree has always guided the architectural education. In addition, the user's needs in the luminous environment related to visual comfort and the impact of light on the architectural space have now gained the significance in lighting education. As a result, there is a need to use modelling tools to predict the visual comfort conditions and spatial quality at the early design stages. This highlights the importance of the evidence-based design approach which selectively embraces the use of meaningful design tools.

This paper presents the teaching and learning experiences in architectural education through effective use of analogue and digital simulation tools for meaningful parametric analysis in spatial and daylighting design and research. The first and second parts of the paper contain a literature review. The first part discussed the benefits of using simulation tools throughout the spatial and daylighting design process in order to assist decision-making. The second part explained how to integrate meaningful testing into the teaching and learning of architectural and daylighting design. Then the literature review is followed examples of design projects and research work indicating how qualitative and quantitative analyses of light have been assessed using the analogue and digital simulation tools.

The paper concluded that the evidence informed design approach which involved using design tools in a selective manner and accurate interpretation of the testing results is the key for achieving holistic daylighting design solutions.

**Keywords:** Analogue daylighting simulation, digital daylighting simulation, meaningful testing in design, daylighting design process, spatial design process

## Introduction

The ability to explore and predict the proposed luminous environment during the design process is crucial for avoiding design mistakes. Evaluation of daylighting performance of buildings through simulation is a crucial part of the design process and it can be done through meaningful and selective use of design tools. The requirements of the architecture as a profession have always guided the architectural education (Addleson and Bell, 1968). Besides, technology enhanced learning progresses day by day. That is why, teaching young architectural students how to use relevant daylighting design tools to assist design development is a significant task.

The meaningful testing of spatial and daylighting design can be carried out by the analogue and digital simulation tools. Schiller and Evans described that the studies, in which the physical modeling and digital modeling have been used as complementary to each other. This combination has provided easy visualization of the analyses and assessment of the performance of the design ideas (Schiller and Evans, 2013).

When design is supported with information, which provides data regarding the consequences of different design options, the design decisions can be taken more consciously. Crismond and Adams mentions the significance of research as it can provide a



concrete basis for design (Crismond and Adams, 2012). This is the point that this paper aims to underline. The use of simulation tools can provide the required information, on which the design decision-making can base on. That is why, integration of the simulation tools into education is a noteworthy topic. How students are introduced to using the simulation tools, they use in order to test design ideas, form their initial design based on evidence-based information as a result of the simulation outputs and carry this meaningful testing discipline into their prospective practicing career should be assessed. That is why, this research focuses on the evaluation of the analogue and digital simulation tools for spatial and daylighting design into the educational context. A detailed literature review has been carried out in order to find out the benefits of the simulation tools in the spatial and daylighting process and to research the integration of the meaningful testing into the architectural education. The literature review is followed by the sample part containing the design projects and research works under the titles 'qualitative analysis' and 'quantitative analysis'. Thus achieving holistic daylighting design solutions are evidenced based on meaningful testing and both qualitative and quantitative aspects of light have been assessed during the design process.

### **Use of the simulation tools throughout the spatial and daylighting design process**

The analogue simulation tools involve scale or physical models for testing on a heliodon or under the artificial sky in the lighting laboratory. The physical model testing can provide both qualitative and quantitative assessment of light. In terms of the qualitative assessment, the lighting quality and impact of light on spatial relationships can be observed. As the quantitative analysis, the calculations related to lighting design can be confirmed. As the intersection of the qualitative and quantitative study, the light distribution based on the calculations can be investigated (Addleson and Bell, 1968).

The digital simulation tools guide the design professionals throughout the design decision-making starting from the early stages of the design process. The holistic design approach highlights the contradicting requirements in the design process between different measures of comfort and energy. Enhancing daylight can affect thermal comfort and increase cooling energy. Building simulation tools are used in order to unite the measures that are related to each other and reach the final design (Østergård et al., 2016). The holistic design considering the visual and thermal comfort requires optimization studies, in which these different comfort and energy measures are evaluated concurrently. Increasing the penetration of daylighting can enhance visual comfort, spatial quality and reduce the artificial lighting energy consumption. However; at the same time, this design option could affect thermal comfort negatively and increase the cooling energy consumption by the increase in the solar gains. The optimization is based on maximizing user comfort, both visual and thermal comfort, and minimizing building energy demand. Simulation tools can support the optimization process effectively. Functions of the building determine the comfort requirements and energy demand. Studies have worked on the comfort and energy optimization for different building functions. As for the educational function, Ferrara et al. (2015) and Zhang et al. (2017) investigated how to obtain thermal and visual comfort while decreasing the energy demand through simulation studies. In the office function, Costanzo and Donn worked through daylighting, thermal and computational fluid dynamics (CFD) simulations in order to assess the performance of naturally ventilated office buildings in different climates in terms of thermal and visual comfort (Costanzo and Donn, 2017). When designing the perforated shading element on the facade of an office space, Chi et al.

worked on optimizing the daylighting performance and building energy consumption. This task was conducted through carrying out daylighting and energy simulation at the same time (Chi et al., 2017). As for the residential function, Carlucci et al. (2015) coupled multi-objective optimization technique with the simulation studies assessing thermal and visual comfort.

Design is not performed on a linear working schedule that architect, engineers and consultants work consecutively. The digital simulation tools support the integrated and simultaneous work process of the professionals. Facilitating the multiple analyses of the design ideas during the design process starting from the early stages have been benefits of the digital simulation tools (Watson, 1997).

There is a significance of the daylighting metrics during the assessment of daylighting through the use of simulation tools. Treacy argues that the daylighting metrics and their analysis should be an integral part of the design process starting from the early stages in order to provide a sustainable daylighting design. The author also looked at the relation between the daylighting metrics and the simulation tools and proposed that the simulation tools should be encouraged, which can analyze the basic principles of daylighting design in the early design process as convenient to the way an architect works (Treacy, 2017).

### **Integrating the meaningful testing of light and space into education**

In architecture, there has been a detachment between technology and aesthetics. While the main frame of architectural discussions was the aesthetics, the awareness of technology and environmental impact was neglected (Watson, 1997). However, light affects facade configuration, spatial appearance and visual comfort of occupants in an architectural space holistically. That is why, design of a lighting system and its education requires competence both on architectural technology and aesthetics of the space.

The way information and experience is transferred has been changing, in both secondary and higher education. The more engaged in an interdisciplinary frame the curriculum is arranged, the more comprehensive the students' learning would be. As for the secondary education, a study compares the environmental attitudes of children between 10 and 12 years old in one sustainable school building and one conventional school building. The environmental and sustainable measures became powerful when students became engaged with them, i.e. through the design of their educational building as a "*pedagogic tool*" (Tucker and Izadpanahi, 2017; p. 215). In another study, poem and photograph analyses encouraged the learning of the students between 16 and 17 years old related to sustainability in a geography course, which turned into a more pleasing experience and an inter-disciplinary task (Walshe, 2017). As for the higher education, following the advancing technologies and changing ways of working, architectural education is changing as well. Addleson and Bell underlined that education must shape "*a thinking person*" who was competent with advancements in the profession and educated being in relation to the practice (Addleson and Bell, 1968; p. 122). Today, discussing urgent topics and teaching distinct skills should be integrated into education (Cheng, 2014). According to Brncich et al., sustainable design and construction becoming extensive affects the higher-education curriculum. The assignments should contain interdisciplinary work with integrated teaching methodologies and communication (Brncich et al., 2011).

The multi-faceted aspects of light in architecture, which contain qualitative and quantitative aspects, prove why the meaningful testing should be integrated into education. According to Mansfield, the significance of lighting education is due to the fact that light

plays an important role in our lives. The author underlines that it is the lighting courses, where students learn about light collaboratively. Besides the involvement of the learning materials, the learning of students should be validated during these courses. Seminars, workshops and research works are the mediums, through which the learning materials are delivered to students (Mansfield, 2017). Besides being the learning tools, the analogue and digital simulation tools can be used for justifying the learning of students and reviewing their design ideas as these tools contain evidenced-based information.

How a student is educated on lighting would affect how he or she utilizes light in the future designs as a professional. Integration of simulation tools into the educational context can help to bridge the gap between the theoretical knowledge and practicing in real world. This is especially significant in both the undergraduate and postgraduate education. It is especially vital to teach students to embed the simulation tools into both early design and advanced design processes. In order to gain the most out of this experience, working in an interdisciplinary manner would be an asset. Assessing the spatial quality, the quality of the luminous environment, the visual comfort of users, the sustainability measures, the furniture layout as part of interior design, the building services systems related to lighting, the maintenance of the lighting systems through facility management holistically through the simulation tools could teach the interdisciplinary approach to students. Considering the sustainability measures, Vallet et al. indicated that learning eco-design should contain different life cycles of the project considering its impact on environment, user and wider society. The attention can be on a particular stage of the project life cycle, so-called "*cradle to gate*", "*gate to grave*", or the whole life cycle of the project, so called "*cradle to grave*" (Vallet et al., 2014; p. 351).

According to Berardi et al., undergraduate architectural engineering students highly benefited from the use of digital lighting simulation. The students worked on designing the lighting system of an existing art museum considering the amendment of the paintings' luminaires, life cycles of products and energy savings. Working on a case study through the guidance of simulation tool provided the students to work as if they had faced a real-world design problem in the professional context (Berardi et al., 2014). A more strong connection between theory and practice can turn the learning experience into a more appealing process. Representing the simulation tools and exercises using these tools as games can encourage the appealing process (Reinhart et al., 2012).

Mitrache discussed how physical modeling and analysis of light through the models affected the design studio process. Maurice Merleau-Ponty indicated that communicating with our environment was established through comprehension that was provided through direct experience. Mitrache referenced this discussion as the basis of spatial sensibility and mentioned that architectural education should contain progressing this skill. As supporting the traditional design teaching methodologies, spatial sensibility can help understanding the experience of body in the created environments. In terms of light; perception of colour, texture, sparkle of light and movements in a space can be taught through spatial sensibility. In the design studio experience of the author, physical models using cardboard were built in scale 1:1. Indicating the model making as a superior instrument for teaching spatial sensibility, the students of this design studio tested the penetration and movement of the natural light on the sunny terrace of the university using these models. Thus, they were able to observe the senses they created and revised the design, accordingly the model, in order to achieve the senses they desired (Mitrache, 2013).

The use of the meaningful testing in design curriculum has impact on the teaching approach as well as affecting the learning process. Zuo et al. revealed the changing role of instructors through the integration of performance-based design into design education. In the experience of an undergraduate interior design project on the spatial and lighting design of dwelling function, which contained the use of the analogue and digital tools, the instructors became “*co-explorers*” within the design process involving participation and experience (Zuo et al., 2010; p. 276).

Literature shows a strong alliance between education and lighting modelling. Ochoa et al. indicated that the use of lighting simulation in education depended on the developments of these models. Learning the accurate design principles and being aware of the collaborative design work have been identified as the benefits of integrating lighting modelling into the education (Ochoa et al., 2012). There is also a strong alliance between education and use of daylighting metrics. Educational design studio workshops and field trips are indicated as beneficial platforms for learning the use of daylighting metrics in the design process in the educational context (Treacy, 2017).



### **The use of simulation tools during the assessment of daylighting: Qualitative sample work**

In the educational context, the qualitative analysis of daylighting system involves the assessment of light distribution on scale and digital models. The sample research work was carried out in the frame of the ‘Master of Architecture (MArch)’ dissertation ‘The Study of Light in Louis I. Kahn’s Museums’. The physical and digital models of the compared three art gallery and museum buildings designed by Louis I. Kahn were built during the research. The studied buildings were the Yale University Art Gallery, the Kimbell Art Museum and the Yale Centre for British Art. In terms of the analogue simulation, the qualitative analysis using the physical model was based on taking pictures from the model located on the heliodon and under the artificial sky using a digital camera. The pictures taken on the heliodon represent the shadow analysis for the Summer Solstice, Equinox and Winter Solstice times. The pictures taken under the artificial sky conditions represent the distribution of light under the overcast sky conditions. In terms of the digital simulation, the three-dimensional models of the buildings were built and daylighting simulations were carried out using a validated lighting simulation tool RADIANCE. When the luminous environment of the gallery spaces was evaluated through the outputs of the analogue and digital simulations, the photographs from literature guided the assessments. The simulation outputs and the qualitative assessments of light are described in Table 1.

### **The use of simulation tools during the assessment of daylighting: Quantitative sample work**

Similar to the qualitative assessment, the quantitative analysis of the daylighting system has been conducted using the physical and digital models of the three art gallery and museum buildings of the masters’ degree research work ‘The Study of Light in Louis I. Kahn’s Museums’. In terms of the analogue simulation, the interior and exterior illuminance measurements were carried out using the scale models under the artificial sky. In terms of the digital simulation, the quantitative analysis contained the daylighting illuminance and brightness contrast studies through the illuminance and luminance simulations. The simulation outputs and the quantitative assessments of light are described in Table 2.

Table 1. The sample work in the educational context describing the qualitative assessment of light through the use of the analogue and digital simulation tools (models, simulations and images by the author)

Degree of work	Title of work	Type of simulation	Simulation Output	The qualitative assessment of light
MArch dissertation	The Study of Light in Louis I. Kahn's Museums	Analogue simulation	 <p>The image of the gallery space in the Yale University Art Gallery, represented through the physical modelling under the artificial sky</p>	The impact of sidelight can be perceived apparently. The daylight penetrating through the floor-height transparent facade drops towards the deeper zones of the gallery space. The end and side opaque walls, which were made of brick and concrete respectively, are observed darker than the zones close to the facade.
			 <p>The image of the side-lit gallery space in the Kimbell Art Museum, represented through the physical modelling under the artificial sky</p>	The distribution of light indicates the impact of the architectural elements as the rooflight and lightcourt. The daylit environment can be observed as hosting the diffuse light penetrating through the rooflight. As supplementary, the sidelight comes from the lightcourt on the right-hand side of the gallery space.




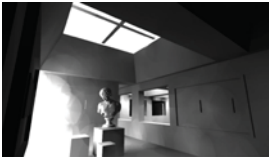
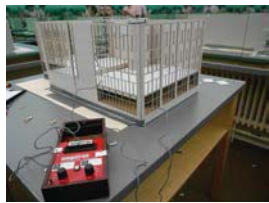

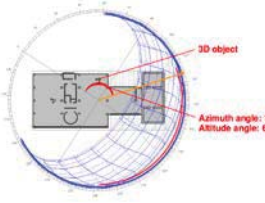
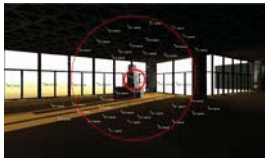
		Digital simulation	 <p>The gallery space of the Yale University Art Gallery under overcast sky condition</p>	The non-uniform light distribution is revealed in the luminous environment of the gallery, where the brightly lit glazed facades are in contrast with the stark dark interior.
			 <p>The facade and the court openings of the gallery spaces in the Yale Centre for British Art under overcast sky condition (RADIANCE simulation)</p>	On the top-floor gallery space, the rooflight has a prominent impact on the well-daylit luminous environment. The sidelight from the window and the light court enhances the three-dimensional modelling of the exhibit.

Table 2. The sample work in the educational context describing the quantitative assessment of light through the use of the analogue and digital simulation tools (models, simulations and images by the author)

Degree of work	Title of work	Type of simulation	Simulation Output	The quantitative assessment of light
MArch dissertation	The Study of Light in Louis I. Kahn's Museums	Analogue simulation	 <p>The analogue simulation of the Yale University Art Gallery under the artificial sky</p>	The interior illuminance level measurements were done as spot measurements on the grid points in the gallery spaces. The measured illuminance levels were compared with the required illuminance levels

			 <p>The analogue simulation of the Kimbell Art Museum under the artificial sky</p>	<p>in the codes. The illuminance levels on wall surfaces of the galleries provided the minimum level indicated as 50 lux for <i>“the perception of detail and colour”</i> in The SLL Lighting Handbook (SLL, 2009; p.199).</p>
		Digital simulation	 <p>The key plan of the Yale University Art Gallery with the sun path analysis indicating the solar position and azimuth &amp; altitude</p>  <p>The selected luminance readings of the Yale University Art Gallery under sunny sky for Winter Solstice 8am, presented in numerical values</p>	<p>According to the sunpath analysis, the low angle morning sun might potentially cause glare in the gallery space orientated towards north-east &amp; south-east. The luminance ratio between task and its immediate &amp; far surround was 1.7 : 1.5 : 1. It was within the recommended luminance ratio 10 : 3 : 1 (Hopkinson, 1966) as no excessive brightness contrast. The contrast of 3D object to its far surround was 2 : 1 with a good 3D modelling. The corner space lit by two glazed facades was one of the desirable positions for displaying 3D art work.</p>

## Discussion

Technical knowledge and experience are significant requirements to utilize the metrics and modelling tools into the daylighting and spatial design process. Educating the undergraduate and graduate students on the daylighting modelling skills would be an asset for the skilfully and conscious use of these tools. In terms of the analogue simulation; the appropriate scale of the physical model and the materials that are used for representing the surface reflectance are crucial to obtain the testing results as accurate as possible. In terms of the digital simulation, the professional should be aware that simplifying the model would directly affect the simulation time and effort.

Interaction between the simulation tools and various types of users are among the enhancements listed for these tools. Besides, realization of user targets has been underlined considering the development of the tools and it was mentioned that the lighting simulation

tools should be part of the building simulation tools together with contributing to the entire design process (Ochoa et al., 2012).

Boyce revealed the different types of lighting quality as bad lighting, indifferent lighting and good lighting. The bad lighting does not consider the requirements established by the lighting codes and guidance. The indifferent lighting concentrates on providing the lighting conditions quantitatively, defined as "*the province of the computer*" (Boyce, 2006; p. 284). The good lighting connects lighting with the temporal and spatial aspects of architecture through the collaboration of the architect and the lighting designer (Boyce, 2006). As mentioned by Boyce (2006), going beyond the quantitative lighting requirements and combining them with the qualitative aspects of light is significant for a desirable lighting quality. The simulation tools, both the analogue and digital tools, should guide the design professionals through the collaborative decision-making of the luminous environment considering the qualitative and quantitative aspects of light. The tools should provide the holistic platform for evaluating both the qualitative and quantitative assessment of the lit spaces.

Collaborative learning can be integrated into education through lighting courses (Mansfield, 2017). On the other hand, literature also underlined the complexities of collaborative work such as forming a shared communication medium between the collaborators (McMahon and Bhamra, 2016). At this point, the simulation tools can be used as the shared platform between the partners of the collaboration. In the educational context, the use of the analogue or digital lighting simulation tools by the students can help solving the complexity of collaboration. The use of the same tool among the students of the same module would allow the comparison of each project output and review of the design solutions in a methodical approach. This would definitely advance collaboration and sharing of ideas between the students. In their study, Gale et al. found out that the attitude of students towards collaborative learning and sustainable approach in the industry differs based on their level in the educational process (Gale et al., 2014). The use of lighting simulation tools can be distinguished according to the level and needs of students. Thus, lighting simulation can become an instrument to enhance collaborative teaching and learning experience.

Schneider et al. mentions the integration of social and humanity sciences into engineering education in addition to critically investigating their engineering field (Schneider et al., 2008). This is an indication that lighting simulation can support because lighting simulation can be utilized for both qualitative and quantitative analysis.

## Conclusion

This paper concluded that the meaningful testing which involved using validated design tools in a selective manner and accurate interpretation of the obtained testing results is remarkable for the daylighting assessment of the architectural projects. Having the opportunity of applying this evidence based design approach for both the qualitative and quantitative assessment of light should be underlined. This provides the holistic analysis of the daylighting systems and thus the daylighting design strategies can be revised holistically.

Reflecting the meaningful testing and evidence based design approach holistically onto the educational context has become one of the essences in the curricula. Hence the students would be able to utilize the simulation tools during their design and research works. This discipline of using the analogue and digital simulation tools for spatial and daylighting design provide integrating the meaningful testing into their own design

processes in the early phases. Moreover, the students would transfer this discipline from the educational context into their prospective professional practice as a technical skill and design asset.

## References

- Addleson, L. and Bell, J. (1968). Lighting in architectural education. *IEStrans*, 33 (4), pp. 119-140.
- Berardi, U. et al. (2014). Acoustics and Lighting Education in Architectural Engineering: Experience of WPI. *Journal of Architectural Engineering*, 20 (2), pp. 05013003-1 - 05013003-9.
- Boyce, P. R. (2006). Education: the key to the future of lighting practice (The Trotter-Paterson memorial lecture presented to the Society of Light and Lighting, London, 21 February 2006). *Lighting Research & Technology*, 38 (4), pp. 283-294.
- Brncich, A. et al. (2011). Using Integrated Student Teams to Advance Education in Sustainable Design and Construction. *International Journal of Construction Education and Research*, 7 (1), pp. 22-40.
- Carlucci, S. et al. (2015). Multi-objective optimization of a nearly zero-energy building based on thermal and visual discomfort minimization using a non-dominated sorting genetic algorithm (NSGA-II). *Energy and Buildings*, 104, p. 378-394.
- Cheng, R. (2014). Designers Designing Design Education. *Journal of Architectural Education*, 68 (1), pp. 12-14.
- Chi, D. A. et al. (2017). Design optimisation of perforated solar façades in order to balance daylighting with thermal performance. *Building and Environment*, 125, 383-400.
- Crismond, D. P. and Adams, R. S. (2012). The Informed Design Teaching and Learning Matrix. *Journal of Engineering Education*, 101, No. 4, pp. 738-797.
- Ferrara, M. et al. (2015). A simulation-based optimization method for the integrative design of the building envelope. *Energy Procedia*, 78, p. 2608-2613.
- Gale, A. J. et al. (2014). The Burnout Phenomenon: A Comparative Study of Student Attitudes Toward Collaborative Learning and Sustainability. *Journal of Interior Design*, 39:1, p. 17-31.
- Hopkinson, R. G., Petherbridgde, P. & Longmore, J. (1966). *Daylighting*. London: Heinemann.
- Mansfield, K. (2017). Opinion: The perplexities of lighting education. *Lighting Research & Technology*, 49 (2), pp. 132.
- Mitrache, A. (2013). Spatial sensibility in architectural education. *Procedia - Social and Behavioral Sciences*, 93, pp. 544 – 548.
- McMahon, M. and Bhamra, T. (2016). Mapping the journey: visualising collaborative experiences for sustainable design education. *International Journal of Technology and Design Education*, published online: 02 March 2016. doi: <https://doi.org/10.1007/s10798-016-9365-0>
- Ochoa, C. E. et al. (2012). State of the art in lighting simulation for building science: a literature review. *Journal of Building Performance Simulation*, 5 (4), pp. 80-95.
- Østergård, T. et al. (2016). Building simulations supporting decision making in early design – A review. *Renewable and Sustainable Energy Reviews*, 61, pp. 187–201.
- Reinhart, C. F. et al. (2012). Learning by playing – teaching energy simulation as a game. *Journal of Building Performance Simulation*, 5 (6), p. 359-368.
- Schiller, S. and Evans, J. M. (2013). From Theory and Research to Education and Practice for Sustainable Building. In: *Proceedings of Building Enclosure Sustainability Symposium BESS-SB13 CALIFORNIA: Advancing Towards Net Zero*, Pomona, California, USA, 24<sup>th</sup>-25<sup>th</sup> June 2013.
- Schneider, J. et al. (2008). Where is 'Community'? Engineering education and sustainable community development. *European Journal of Engineering Education*, 33:3, p. 307-319.
- The Society of Light and Lighting (SLL) (2009). *The SLL Lighting Handbook*. London: SLL.
- Treacy, G. (2017). Sustainable Lighting Design – Appropriate metrics for built environment education? In: Brotas, L., Roaf, S. and Nicol, F. (eds), *Proceedings of 33<sup>rd</sup> PLEA International Conference: Design to Thrive*, Volume II. Edinburgh, United Kingdom, 2<sup>nd</sup>-5<sup>th</sup> July 2017, London: Network for Comfort and Energy Use in Buildings (NCEUB) 2017.
- Tucker, R. and Izadpanahi, P. (2017). Live green, think green: Sustainable school architecture and children's environmental attitudes and behaviors. *Journal of Environmental Psychology*, 51, p. 209-216.
- Vallet, F. et al. (2014). Proposal of an eco-design framework based on a design education perspective. *Procedia CIRP*, 15, pp. 349 – 354.

Walshe, N. (2017). An interdisciplinary approach to environmental and sustainability education: developing geography students' understandings of sustainable development using poetry. *Environmental Education Research*, 23:8, p. 1130-1149.

Watson, D. (1997). Architecture, Technology, and Environment. *Journal of Architectural Education*, 51 (2), pp. 119-126.

Zhang, A. et al. (2017). Optimization of thermal and daylight performance of school buildings based on a multi-objective genetic algorithm in the cold climate of China. *Energy and Buildings*, 139, p. 371-384.

Zuo, Q. et al. (2010). Integrating performance-based design in beginning interior design education: an interactive dialog between the built environment and its context. *Design Studies*, 31 (3), pp. 268-287.



*Chapter 6:*  
*Renewable energy technologies*  
*Sustainable construction and technology*

# Influence of energy-use scenarios in Life-Cycle Analysis of renovation projects with Building-Integrated Photovoltaics – Investigation through two case studies in Neuchâtel (Switzerland)

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**Abstract:** Since tomorrow's cities are already largely built, and as many of their buildings – with a low level of energy performance – will still be standing in 2050, urban renewal processes play an essential role towards the sustainable development of European cities. In this context, Building-Integrated Photovoltaic (BIPV) systems can potentially provide a crucial response for achieving long-term carbon targets. Functioning both as envelope material and on-site electricity generator, they can simultaneously reduce the use of fossil fuels and greenhouse gas emissions. Focusing on the architectural design, this paper presents the results of a multi-criteria evaluation in terms of Life-Cycle Assessment (LCA) and Cost (LCC) of different renovation and energy-use scenarios. The goal is to identify which strategies can allow to achieve the ambitious targets for the 2050 horizon by integrating into the design process: **1) Passive strategies**, to improve the envelope through low-embodied energy materials and construction systems; **2) BIPV strategies**, using innovative photovoltaic products as a new material for façades and roofs; and **3) Active strategies**, adapting HVAC systems to improve the efficiency of the BIPV installation and reducing the dependence on the feed-in-tariffs to ensure the profitability of investments. An emphasis is placed on testing the impact of a proposed selection process of BIPV surfaces in order to maximise self-consumption and self-sufficiency, evaluating the effect of electricity storage systems with and without the possibility of injecting the overproduction into the grid. Our methodology and results are presented through the comparison of two real case studies in Neuchâtel (Switzerland). Proposing a new approach to address renovation projects of existing buildings in the urban context towards Low Carbon Buildings, the outcomes provide architects and engineers with advanced BIPV renovation strategies depending on the building typology, the architectural design goals and the level of intervention.

**Keywords:** Building renovation, Building-Integrated Photovoltaics, integrated design, multi-criteria assessment, Life-Cycle Assessment

## Introduction

Many strategies stress the importance of urban renewal processes towards more sustainability (Riera and Rey, 2013) (Aguacil et al, 2017a). Indeed, there are still considerable potential energy savings to be made in European countries in general, and in Switzerland in particular, where most residential buildings were built before 1985 and require large amounts of energy to ensure the minimum indoor thermal comfort (OFS, 2017). In response, one of the objectives of the “2000 Watt society” (SIA, 2011) – a concept that promotes an annual limit per person of 1 tonne of CO<sub>2</sub> emissions and 2000 W expressed in mean power – is to drastically reduce greenhouse gas (GHG) emissions taking into account the whole life cycle of buildings. Building-Integrated Photovoltaic (BIPV) systems represent a promising solution to the energy turnaround challenges (SFOE, 2017), as it is estimated that photovoltaics (PV) could cover up to 1/3 of the annual Swiss electricity demand (IEA, 2002).

BIPV is a growing and diverse area of research, as confirmed by the development of new products and their integration on building envelopes (Frontini et al, 2012). Despite this technological progress, only a small part of the available local PV potential is exploited in urban areas. Different types of obstacles limit a large-scale PV integration into urban renewal processes, namely, the limited motivation of architectural designers, a restricted knowledge

of the BIPV potential, and an insufficiency of aesthetically-convincing exemplary buildings (Heinstein et al, 2013). To address these challenges, architectural design towards increased integration – and therefore increased acceptance – must be supported. Therefore, instead of considering BIPV as a technical constraint for designers, we propose a new approach based on the integration of BIPV solutions as a new “raw material” (Aiulfi and Rey, 2010). Prioritizing architectural quality and dialogue with the built environment, it aims at identifying which construction elements can be substituted by PV components, fulfilling the building envelope requirements while producing electricity on-site from a renewable energy source.

This paper is an integral part of an ongoing research project entitled ACTIVE INTERFACES, which aims at studying the technological, spatial, legal and socio-economic parameters related to the development of new adapted BIPV solutions (Rey et al, 2015).

Based on the architectural design strategies already developed in the first step of the project and published in Aguacil et al (2016, 2017b), we here present the impact on the final performance of an optimization process based on an annual irradiation threshold to choose the active surfaces for two case studies in Neuchâtel (Switzerland).

## Research methodology

The methodology involves four main phases: 1) selection of archetypal residential buildings; 2) detailed analysis of each building; 3) development, for each archetype, of four architectural renewal scenarios embodying different levels of intervention; 4) multi-criteria assessment of the scenarios. As further details on the methodology and the detailed façade designs to obtain aesthetically convincing examples can be found in Aguacil et al (2016, 2017b), the first three phases are briefly described below in reference to the two presented case studies. The emphasis is more focused on the description of the multi-criteria assessment (phase 4), which is the central purpose of this paper.

### *Phase 1: Selection of an archetypal building*

Considering Neuchâtel as a representative city of the Swiss Plateau (OFS, 2015) and based on its building stock analysis, five residential archetypes have been identified, using selection criteria such as the construction period and heritage protection level. A representative building for each archetype was chosen to carry out a series of real case studies.

### *Phase 2: Detailed analysis of the buildings*

The case studies presented in this paper are two multi-family residential buildings that correspond to residential archetypes 1 and 4. In their current status, to which we will refer as situation **E0**, both buildings, shown in Figure 1, present a low level of energy performance.



**Archetype 1**  
Built in 1909  
4 stories  
8 apartments  
788 m<sup>2</sup> floor area



**Archetype 4**  
Built in 1972  
11 stories  
52 apartments  
5'263 m<sup>2</sup> floor area

Figure 1. Images of the current status of each building along with their main characteristics.

**Archetype 1** has an uninsulated envelope; its façades consist of 40 cm thick rubble masonry walls and exterior plaster, windows are single glazing and the sloped roof is finished with ceramic tile (Aguacil et al, 2017b). **Archetype 4** has a poorly insulated envelope; its façades are made of prefabricated concrete elements with 4 cm of expanded polystyrene (EPS)

insulation, double-glazed windows and a flat roof with 6 cm of EPS insulation and 5 cm of gravel (Aguacil et al, 2016). In terms of active systems, both buildings have a central oil boiler covering heating and domestic hot water (DHW) needs.

### ***Phase 3: Design of architectural renewal scenarios***

Starting from **E0-Current status**, we define four renewal scenarios from an architectural and energy point of view. The **S0-Baseline** scenario aims at achieving at least the current legal requirements defined by SIA 380/1:2016 (SIA, 2016), in accordance with current practices and only through passive strategies to reduce the energy demand (by improving the performance of the envelope using low-cost materials).

The other three design scenarios incorporate BIPV in addition to passive strategies using more ecological materials such as recycled EPS insulation or wooden frames for windows. For **S1-Conservation**, the goal is to maintain the expression of the building while improving its energy performance (at least up to current legal requirements) and respecting the targets to obtain a subsidy of 60 CHF/m<sup>2</sup> from the “programme bâtiment” which promotes energy renovation of existing buildings (EnDK, 2015). For **S2-Renovation**, the general expressive lines of the building are to be maintained while reaching high-energy performance (taking as reference the Swiss Minergie® label (Minergie, 2016)). For **S3-Transformation**, the aim is to achieve the best energy performance and maximum electricity production possible with aesthetic and formal coherence over the whole building (at least “2000 Watt Society” (SIA, 2011)).

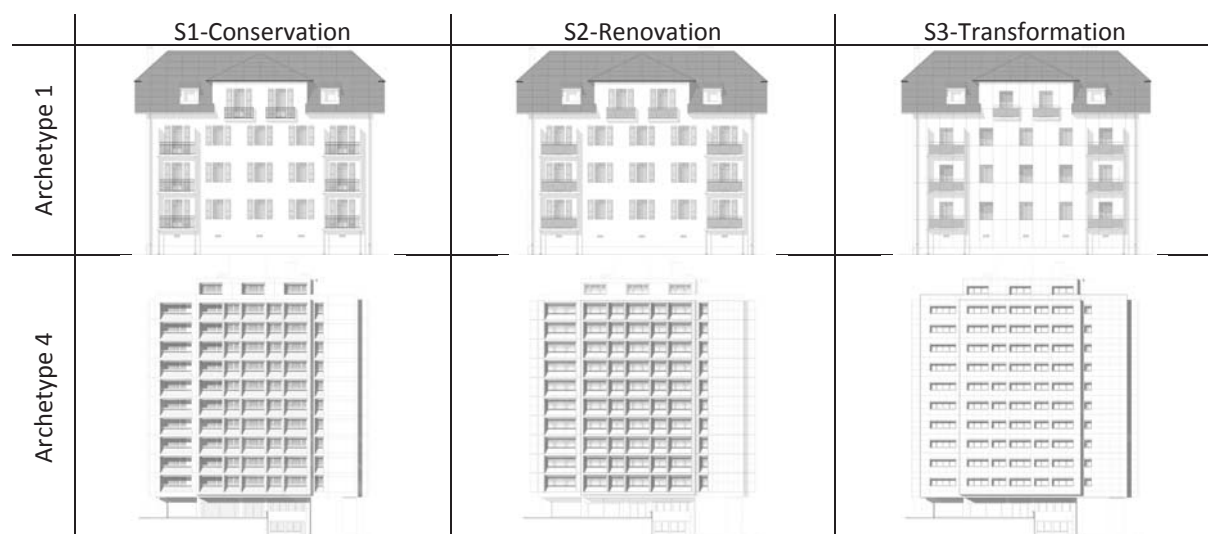


Figure 2. Main façade definition for each BIPV scenario, detailed in Aguacil et al (2016, 2017b).

In combination with the integration of BIPV in S1 to S3 we propose to implement an additional active strategy consisting in the replacement of the existing oil-boiler by an electricity-based system to increase the self-consumption of the electricity produced on-site and reduce the consumption thanks to high-efficiency air-water heat pumps.

The design process consists in an iterative procedure between design at the construction level and energy simulation in order to continuously verify the final performance of each design proposition. Energy simulations are carried out in DesignBuilder v.5 (DB, 2017), based on the EnergyPlus® simulation engine. In an iterative simulation process, we verify the fulfilment of the objectives set for each scenario, adjusting the constructive details of each

proposal. From the final design (Figure 2), we obtain the hourly consumption of the building during the entire year for each renewal scenario.

#### **Phase 4: Multi-criteria assessment**

One of the main objectives of this research is to define what is the most adequate way to integrate PV elements into the envelope of buildings in renovation projects. To do so, we propose to investigate the influence of three **energy-use scenarios** on the multi-criteria assessment detailed below. Those three scenarios, defined in Figure 3, are: **A)** use 100% of the identified active surfaces; **B)** adjust the amount of active surfaces to the demand of the building by conducting a selection process; and **C)** add batteries given the selected active surfaces obtained in B). A) is obtained following the design phase where we define all potential PV surfaces using standard- or custom-size panels (MB, 2017) with coloured films (CSEM, 2017). Then, for B), a selection process is conducted to define which of these surfaces will finally be covered by BIPV elements versus non-active elements with the same aspect. The selection process begins with a study based on the cumulated annual irradiation threshold. The goal is to identify the annual irradiation threshold which leads to maximizing both the self-sufficiency (energy independence) and self-consumption (level of use of the PV system), two concepts further described in Luthander et al (2015). Surfaces that achieve the optimal irradiation threshold are then considered to be active. For C), in addition to conducting the surface selection of B), batteries (sized for a mean daily demand) are integrated to further increase the self-consumption and self-sufficiency (Swissolar, 2016).

The estimation of the hourly on-site electricity production is done on a detailed 3D model created in the Rhinoceros 3D modelling tool and using the visual programming software Grasshopper with the DIVA plugin (DIVA, 2017).



Figure 3. Comparative energy-use scenarios

In parallel to the design process and through an iterative cycle, we conduct a multi-criteria evaluation based on Life-Cycle Analysis (LCA) and Cost (LCC) to compare the scenarios and evaluate the impact of the active surfaces selection, using simulation and reference values.

The LCA takes into account energy consumption, GHG emissions, on-site PV generation and environmental impact of materials including BIPV elements for a 60-year lifespan (KBOB, 2016). The environmental impact values for construction materials, PV elements, HVAC systems and batteries are obtained with the ECO-BAT software (ECO-BAT, 2017) and a Swiss eco-building database (KBOB, 2016), with a lifetime of 50, 30, 20 and 10 years respectively.

For the LCC analysis, the renovation cost is obtained using the EPIQR tool (Flourentzou et al, 2000), developed to perform the diagnosis of existing buildings and test different renewal scenarios. Subsidies for both the BIPV installation (Swissgrid, 2017) and energy renovation (EnDK, 2015) are taken into account. We use the existing PV technology based on the single-crystal silicon (sc-Si) cell, with 17% efficiency (Cerón et al, 2013). The expected cost is between 245 and 445 CHF/m<sup>2</sup> for standard-size modules and 780 CHF/m<sup>2</sup> for customized



ones, including inverters, wiring and accessories. The estimated cost of batteries is 288 CHF/kWh based on gel technology batteries (Swiss-green, 2017).

The estimation of the global cost-effectiveness is done for a 50-year horizon with a 3% interest rate. The calculation considers energy savings and electricity production, including a 0.8% production decrease per year according to the guaranteed performance of PV elements (MB 2017), and a price of 0.1 CHF/kWh (for heating oil) and 0.2 CHF/kWh (for electricity), tax included. For electricity overproduction injected into the grid, we have considered a cost-covering remuneration (Swissgrid, 2017) between 0.064 and 0.106 CHF/kWh depending on the installation size, scenario, and case study. The payback time is calculated using the DCF (discounted cash flow) methodology by net present value (NPV), considering the real-time self-consumption with no battery systems and the injected electricity overproduction.

## Results

### *Design scenarios implementation for each archetype*

As described in Table 1, for **S0** – representing current practice – the insulation is increased for all opaque surfaces and windows are replaced to achieve current legal requirements (SIA, 2016). For scenarios **S1** to **S3**, in addition to the interventions of **S0**, BIPV elements are integrated on roof and façades taking into account the requirements of the design scenarios defined in phase 3 of the methodology and favouring more ecological materials over low-cost materials.

Regarding the façade definition (Figure 2) of the different BIPV scenarios (S1 to S3), we propose for **archetype 1** an external insulation system with synthetic coating cladding for **S1** and **S2**, with PV elements on roof (S1) and balustrades (S2). In **S3**, a ventilated façade system is implemented using PV elements, prefabricated, modular and built with wooden structure. For **archetype 4**, an internal insulation system covering the railing of windows with customized PV elements is proposed for **S1**, and a ventilated façade system incorporating PV panels on the biggest opaque surfaces for **S2**, in order to reproduce the geometry of the existing façade. For **S3**, a ventilated façade system using PV elements, prefabricated, modular and built with a wooden structure is implemented.

Table 1. Summary of design scenarios implementation for each archetype.

Sc.	Arch.	Type (colour) of materials		Insulation	Target U-value [W/m <sup>2</sup> .K]		Infiltr. [ach]
		Roof	Façades	Thickness (type)	Opaque	Windows	
<b>E0</b>	1	Tiles (brown)	Synthetic coating	-	1.33	5.7 (sg-w)	2
	4	Gravel	Concrete	4 cm (EPS - Int)	1.09	2.6 (dg-a)	
<b>S0</b>	1	Tiles (brown)	Synthetic coating	14 cm (EPS - Ext)	0.25	1.3 (dg-pvc)	1
	4	Gravel	Concrete	10 cm (EPS - Int)			
<b>S1</b>	1	SSz (brown)	Synthetic coating	17 cm (rEPS - Ext)	0.20	1 (tg-w)	0.7
	4	SSz-f (black)	CSz (concrete)	14 cm (rEPS - Int)			
<b>S2</b>	1	SSz (brown)	SSz (ochre)	18 cm (rEPS - Ext)	0.19	0.7 (tg-w)	0.5
	4	SSz-f (black)	CSz (concrete)	15 cm (rEPS - Ext)			
<b>S3</b>	1	SSz (brown)	SSz (ochre)	20 cm (rEPS - Ext)	0.17	0.7 (tg-w)	0.5
	4	SSz-f (black)	SSz (grey)	17 cm (rEPS - Ext)			

Abbreviations: Custom-size (CSz) or standard-size PV panels (SSz), with frame (-f), standard expanded polystyrene (EPS), 100% recycled expanded polystyrene (rEPS), internal (Int) or external insulation (Ext), single (sg), double (dg) or triple glazing (tg), aluminium (-a), polyvinyl chloride (-pvc) or wooden windows frame (-w).

### Active surfaces selection process

To select the active surfaces for the second energy-use scenario (B, see Figure 3), different cumulated annual irradiation thresholds (varying from 0 to 1'200 kWh/m<sup>2</sup>.year) are applied on all possible active surfaces identified from the design phase.

Figure 4 highlights the surfaces that do and do not receive enough solar energy to be considered as active (in scenario S3-Transformation). From these results and the derived self-consumption and self-sufficiency, we identify the optimum threshold and the corresponding annual PV production.

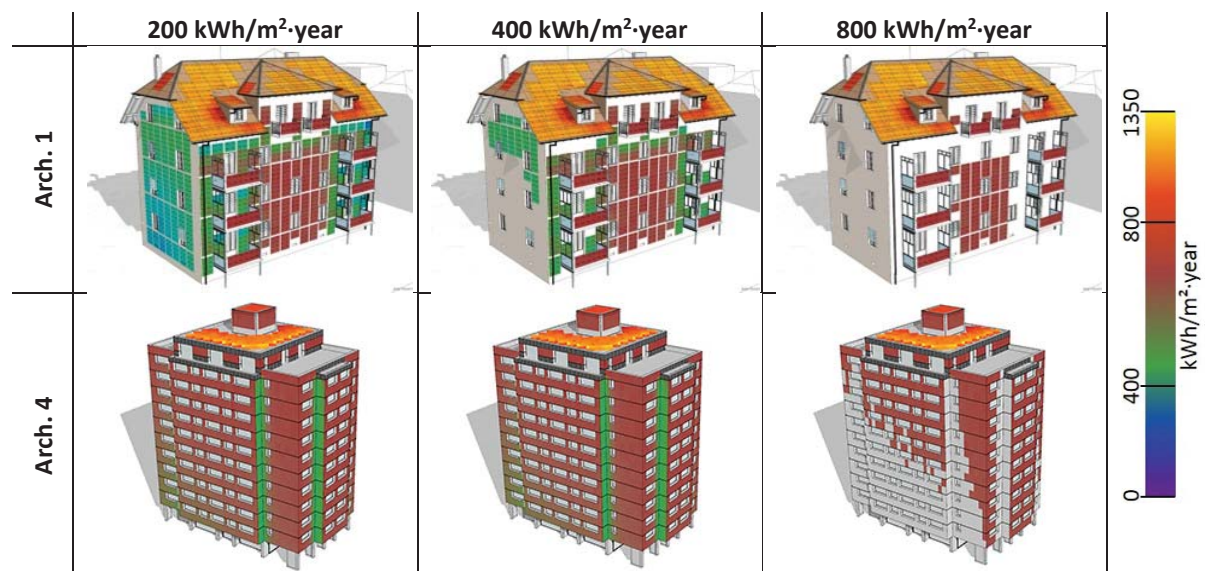


Figure 4. Annual irradiation threshold study for the scenario S3 (SE-SW façades) for archetype 1 (top) and 4 (bottom). Coloured surfaces (according to the scale on the right) reach the threshold values.

For each scenario, two different thresholds are obtained, depending on whether the existing boiler is maintained or replaced. Figure 5 shows an example of optimization results for scenario S3. For **archetype 1**, the threshold is 1'175 kWh/m<sup>2</sup> (oil-boiler) and 800 kWh/m<sup>2</sup> (heat pump), leading to 14 and 28 MWh/year of on-site production respectively, and to 29% of self-consumption and 24.5% of self-sufficiency. For **archetype 4**, the threshold is 800 kWh/m<sup>2</sup> (oil-boiler) and 600 kWh/m<sup>2</sup> (heat pump), for 87 and 139 MWh/year of on-site production respectively, and 32% of self-consumption and 29% of self-sufficiency.

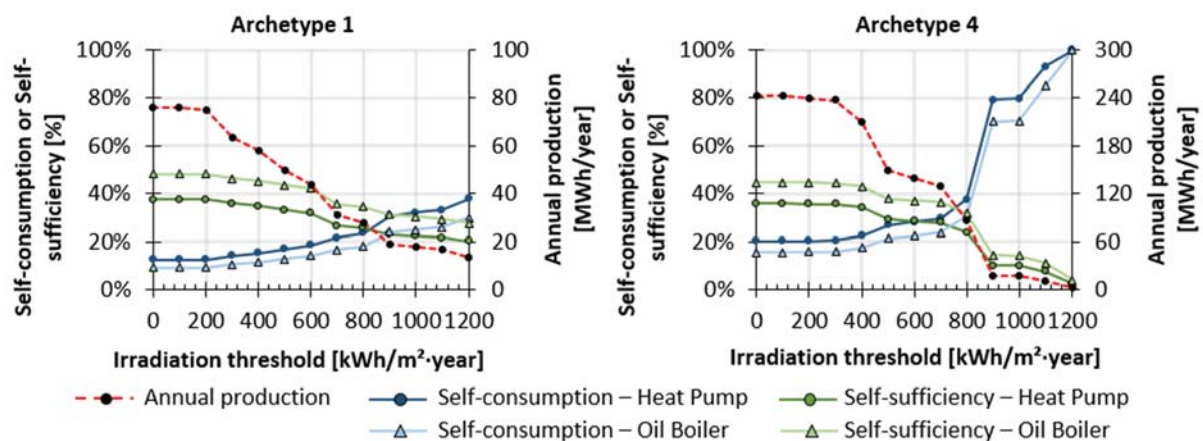


Figure 5. Example of irradiation threshold study based on self-consumption and self-sufficiency for scenario S3.

## Energy-use scenarios

We here present an example of the results obtained for the three energy-use scenarios introduced earlier (Figure 3). Figure 6 shows the daily energy balance (15<sup>th</sup> April) calculated from hourly data for the archetype 1 and for the scenario S3-transformation. With the selection of active surfaces (scenario B) following the procedure described in the previous section, we observe a better balance between self-sufficiency and self-consumption, leading to a trade-off between the two ratios. When batteries are added (C), both ratios increase while guaranteeing one average day of autonomy. Given that a self-sufficiency of 100% is reached for this example, we can deduce that if we were to integrate batteries with the same storage capacity with 100% of active surfaces (on A), we would obtain the same 100% value for self-sufficiency, but a lower self-consumption as more of the produced electricity could not be stored. Therefore, it seems more rational to integrate batteries after a selection of active surfaces has been done, as is the case here with scenario C).

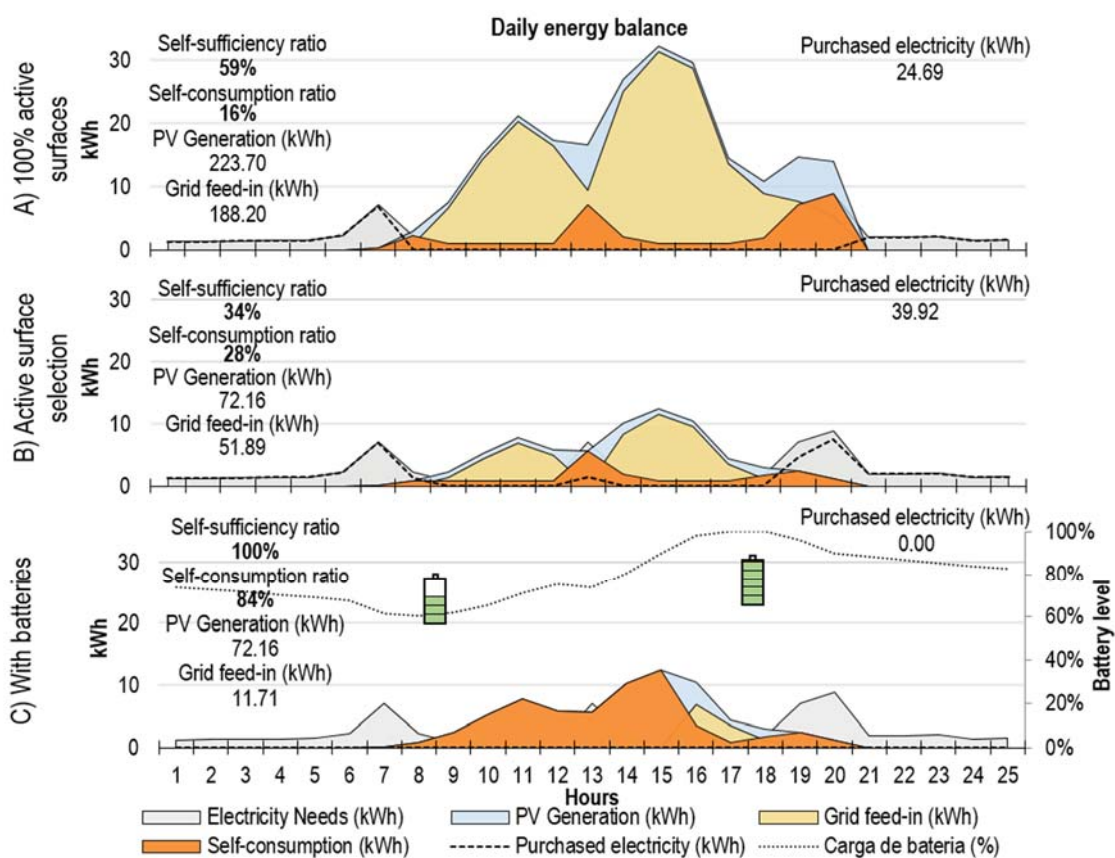
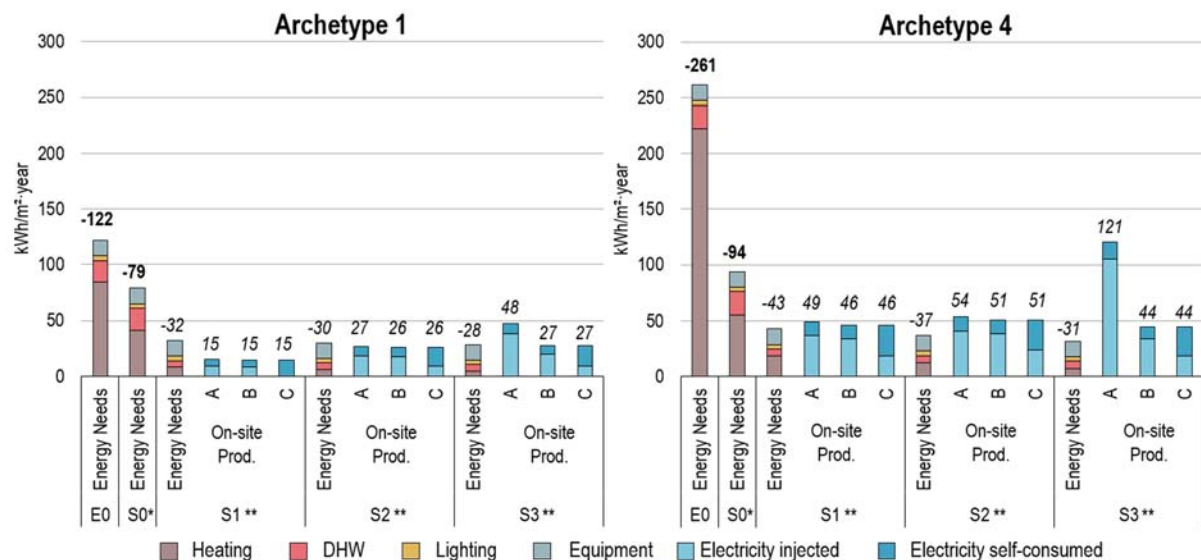


Figure 6. Example of daily energy balance for the three comparative energy-use scenarios (Archetype 1, 15<sup>th</sup> April, scenario S3-transformation).

## Final energy balance

Figure 7 presents the results of the annual final energy balance for all design and energy-use scenarios, including energy needs and electricity produced on-site by the BIPV installation, obtained through hourly simulation. The considerable energy consumption of the current status (E0) highlights the importance of the energy renovation process. In scenario S0, implementing a current practice renovation using the current legal requirements (SIA 380/1:2016) reduces the total energy consumption by 64% and 35% for archetype 1 and 4 respectively. However, the implementation of BIPV scenarios S1 to S3 allows total savings ranging from 77% to 88%.



\* Energy model calibration using real consumption data.

\*\* The BIPV scenarios include the replacement of the current oil-boiler with an electrical-base system (air-water heat-pump).

Figure 7. Final energy balance for each renovation scenario and each energy-use option, A) 100% active surfaces, B) active surfaces selection and C) active surfaces selection with batteries.

In addition to the energy savings induced by improving the envelope performance (passive strategies), S1-S3 produce a considerable amount of electricity on-site, in some cases making the building a positive energy building that produces more energy than it needs.

### Life Cycle Analysis (LCA)

Figures 8 and 9 show the results of the life-cycle analysis of the whole renovation project (passive and active strategies) for the three comparative energy-use scenarios (Figure 3) based on a feed-in tariff approach, injecting the electricity overproduction into the grid (Figure 8), as well as based on a self-consumption approach, without injection into the grid (Figure 9). A comparison is made with the Swiss “2000 Watt society” targets (SIA, 2011) in terms of non-renewable primary energy (CEDnr) and GHG emissions to prevent global warming potential (GWP).

Not included in the figures, and independent from the approach, is the improvement obtained when going from E0 to S0, which is of 60% and 30% in terms of energy consumption and GHG emissions respectively. Observations can first be made regardless of the approach (for both figures). From S0 to S3, as the performance of the buildings increases, the weight of the embodied energy related to the construction materials also becomes more important. Scenarios S1, S2 and S3 respect the Swiss targets. It is also important to highlight the fact that it is only possible to achieve the “2000 Watt society” targets by using low-carbon materials and changing the type of energy source (using an electric heat pump instead of an oil-boiler), which increases the self-consumption of the on-site electricity production. These observations represent key elements toward real carbon neutrality. In addition, the selection process of the active surfaces (B) allows achieving the performance objectives in a more rational way, avoiding the excessive injection of electricity into the grid.

In the case, that we are able to inject the overproduction into the grid (Figure 8), for the energy-use option C), the application of the batteries is less efficient than the sole selection of active surfaces, because by injecting the overproduction we are actually using the grid as a storage system. Consequently, the batteries could be useful exclusively for managing the energy, for example in the case where we would like to import electricity from the grid when



the content of GHG is lower or when the price of electricity is cheaper. Then, batteries would make it possible to do so and help minimize the CED and GWP (Vuarroz et al, 2016).

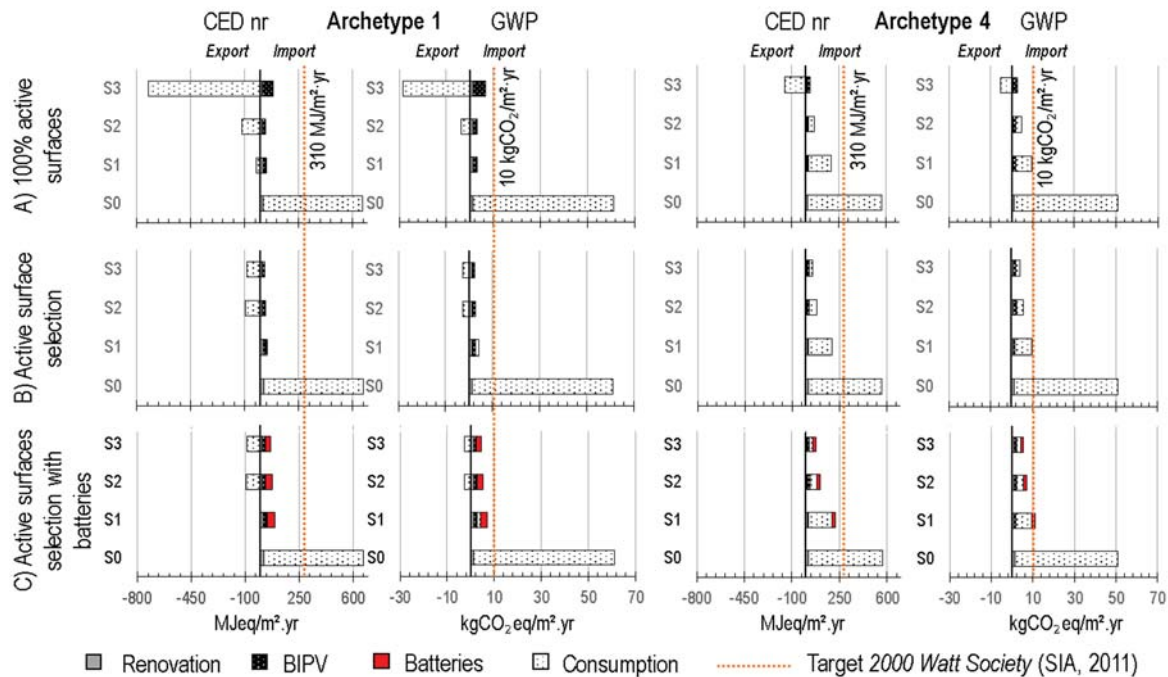


Figure 8. LCA results (**feed-in tariff approach**) in terms of embodied energy, GHG emissions and end-use consumption, taking into account A) 100% of potentially active surfaces, B) selected surfaces and C) batteries.

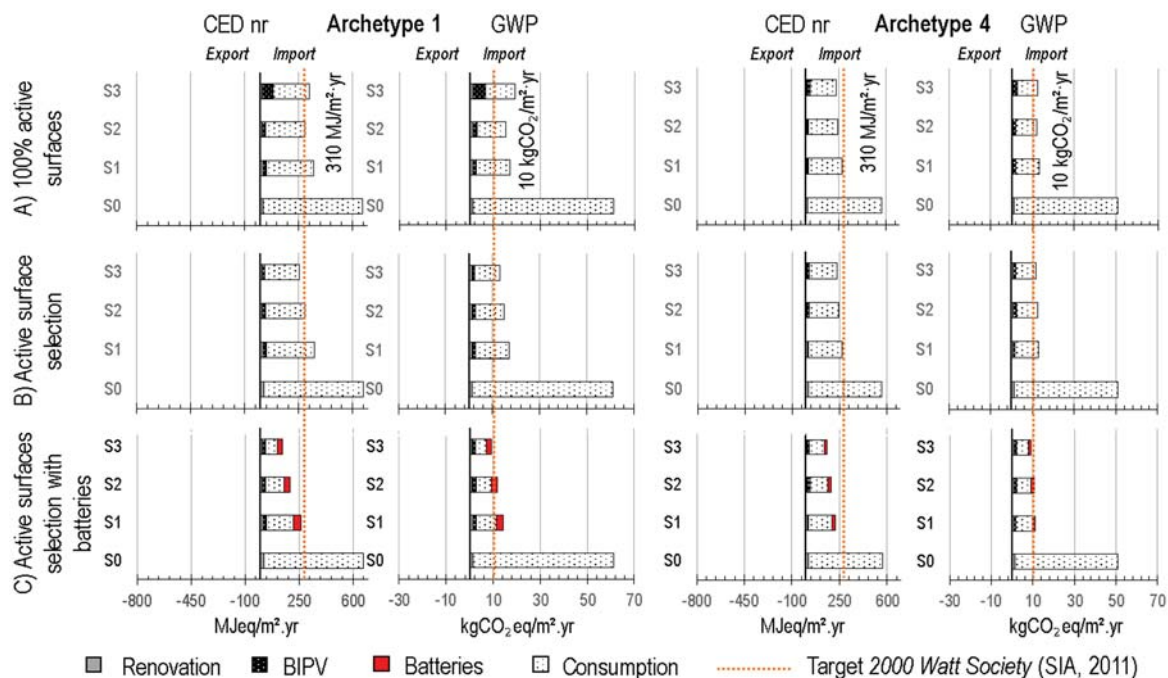


Figure 9. LCA results (**self-consumption approach**) in terms of embodied energy, GHG emissions and end-use consumption, taking into account A) 100% of potentially active surfaces, B) selected surfaces and C) batteries.

In the case that we are not able to inject the overproduction into the grid and must prioritize the self-consumption approach, Figure 9 shows the importance of a reduction of the embodied energy and GHG emission of the BIPV elements via a selection of active surfaces to achieve the Swiss targets. We highlight the important role of the batteries as a system to



increase self-consumption and self-sufficiency, to achieve those targets for both, primary energy and CO<sub>2</sub> emission.

Given our objective of achieving the “2000 Watt society” targets in the most rational way, at least for the design scenario S3-transformation and taking into account the entire life-cycle analysis, Figures 8 and 9 show that the achievement of these objectives is not easy, but is possible. The results depend on the orientation, type, size and context of the building.

### Life Cycle Cost (LCC)

From the study of the two archetypes and the three energy-use scenarios, with and without taking into account the possibility of exporting the electricity overproduction to the grid, Figure 10 shows the difference in terms of payback time of the whole renovation project in function of the energy-use option for both the feed-in-tariff and self-consumption approach.

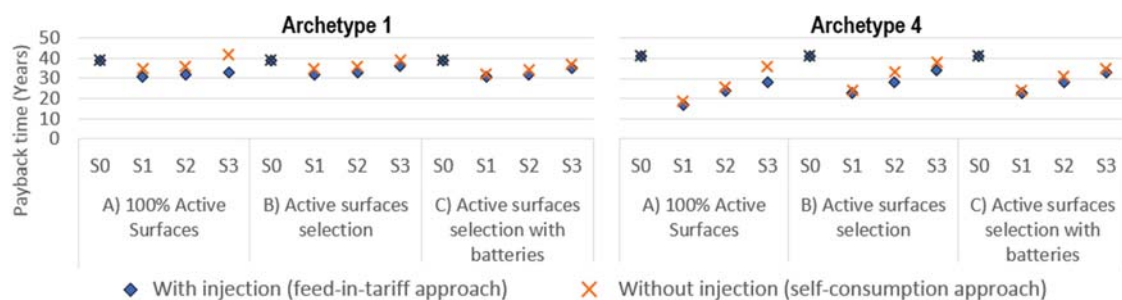


Figure 10. Simple payback time for the two archetypes comparing the three energy-use options with and without taking into account the injection of the electricity overproduction into the grid, substituting the existing oil-boiler by an electric heat-pump for heating and DHW.

Results highlight that, using a feed-in-tariff approach, scenarios S1, S2 and S3, which include BIPV strategies, present in all cases a shorter payback time compared to scenario S0 (standard renovation without BIPV), due to the energy savings and the extra revenue generated by the injected electricity into the grid.

However, when using a self-consumption approach where we are not able to inject the electricity overproduction into the grid, some cases are too close to the payback time of the reference scenario (S0). For archetype 1, the payback time for scenario S3 with 100% of active surfaces exceeds that of the reference scenario (S0) mainly due to the big investment of an oversized BIPV installation with respect to the building's demand, which leads to a too low level of self-consumption (around 9% of the total electricity produced on-site, see Figure 7). Consequently, for this particular scenario, 81% of the electricity produced by the active elements cannot be used by the building or be injected into the grid.

The result of the active surfaces selection process has a more pronounced effect in terms of payback time for archetype 4 due to the larger active surface on façades compared to the active surface on the roof. Above all, in scenario S3 where more PV surfaces are proposed, we observe that the optimization increases payback but avoids excessive electricity injection into the grid. However, S3 continues to be more cost-effective than scenario S0.

After the selection of the active surfaces to maximise self-consumption and self-sufficiency, we tested the introduction of batteries to increase both parameters. Despite the notable increase of the initial investment due to the high price of batteries, the resulting payback time is very interesting to justify the economic viability of batteries in residential renovation projects (Hoppmann et al, 2014). It should be emphasized that, despite not having the possibility of injecting electricity into the grid, the levels of self-consumption and self-

sufficiency are so high (between 60-80%) that the results are comparable to the option where all the overproduction could be sold to the grid.

## **Conclusion**

Today, renovation projects improving the building envelope with a high level of thermal energy performance using passive strategies are necessary, but not sufficient. Compensating buildings' energy consumption and embodied energy of the construction materials by producing electricity on-site has become a number one priority. By proposing new adapted BIPV solutions for urban renewal processes, this research contributes to advancing architectural design practices in this direction.

The results presented in this paper highlight the fact that energy renovation projects in the built environment that do not integrate active elements producing electricity from solar energy to cover as much as possible the energy demand of the building are no longer an option if we want to achieve long-term carbon targets.

The analysis of the two case studies highlights the best cost-effectiveness of the BIPV scenarios and the importance of choosing the location of the active surfaces to maximize the self-consumption and self-sufficiency with respect to the building's consumption profile.

Considering that a disconnection from the grid is not an option because of security supply reasons, the role of storage systems using batteries in this kind of renovation projects offers two possibilities depending on the energy-use scenario that we may face. In a feed-in-tariff approach, where the possibility to sell the energy to the grid exists, the main role of batteries could be in terms of energy management, as there are no advantages in terms of non-renewable primary energy and greenhouse gas emissions. However, in a self-consumption approach, where the possibility of injecting the electricity into the grid could be difficult or impossible, the role of batteries is remarkable, because they help increase the self-consumption ratio by decreasing the energy needs from the grid, reaching the Swiss targets.

These are key elements toward real carbon neutrality, allowing us to achieve the performance objectives in a more rational way by optimising the installation to minimise the grid-injected energy. This in turn allows avoiding the intrinsic problem linked to decreasing prices of injected electricity.

The main limitations of this study lie in the fact that available reference values for the LCA are not up-to-date with respect to the proposed products, yet they represent worst-case values given that improvements are expected in terms of embodied energy of materials. Moreover, only one payback value is obtained in the LCC, whereas a range would be preferred since the payback is sensitive to parameters such as the interest rate and the evolution of energy prices.

The next step in our research is to make high quality visualisation of the different design scenarios for each archetype to show that, apart from the energy efficiency of the solutions, it is possible to give an architectural response to different kinds of situations from the urban context and heritage constraints to maintain the quality of the existing buildings. Ultimately, our case studies shall provide architects, installers and public authorities with a catalogue of innovative and adapted "best practice" solutions for a large-scale advanced BIPV integration into urban renewal processes.

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## References

- Aguacil, S., Lufkin, S. and Rey, E., (2016). *Architectural design scenarios with building-integrated photovoltaic solutions in renovation processes: Case study in Neuchâtel (Switzerland)*. In: 32nd International Conference on Passive and Low Energy Architecture, Los Angeles, USA, 11-13 July 2016.
- Aguacil, S., Lufkin, S. and Rey, E., (2017b). *Holistic design strategies for renovation projects with building-integrated photovoltaics (BIPV): case study from the 1900s in Neuchâtel (Switzerland)*. In: 15th National Photovoltaic Congress 2017, Lausanne, Switzerland, March 23-24 2017.
- Aguacil, S., Lufkin, S. and Rey, E., and Cuchi, A. (2017a). Application of the cost-optimal methodology to urban renewal projects at the territorial scale based on statistical data - A case study in Spain. *Energy and Buildings*, 144, pp.42-60.
- Aiulfi D., Rey E., (2010). *Les technologies vertes, matières premières pour la créativité des architectes*. Neuchâtel: MICRO 10, specialized lectures.
- Cerón I., Caamaño-Martín E., Neila F.J., (2013). 'State-of-the-art' of building integrated photovoltaic products. *Renewable Energy*, 58, pp.127-133.
- CSEM, (2017). *Selective filter technology to coloured modules*. Available: [www.csem.ch](http://www.csem.ch) [22 March 2017].
- DB, (2017). DesignBuilder software. Available: [www.designbuilder.co.uk](http://www.designbuilder.co.uk) [15 March 2017].
- DIVA, (2017). DIVA software. Available: [www.solemma.net](http://www.solemma.net) [30 August 2017].
- ECO-BAT, (2017). Eco-bat software. Available: [www.eco-bat.ch](http://www.eco-bat.ch) [15 septembre 2017].
- EnDK, (2015). *Modèle d'encouragement harmonisé des cantons*. [www.endk.ch](http://www.endk.ch) [22 March 2017].
- Flourentzou F., Droutsas K., Wittchen K.B., (2000). EPIQR software. *Energy and Building*, 31, pp.129-136.
- Frontini, F., Manfren, M., Tagliabue, L.C., (2012). A case study of solar technologies adoption: criteria for BIPV integration in sensitive built environment. *Energy Procedia*, 30, pp.1006-1015.
- Heinstein P., Ballif C., Perret-Aebi L.E., (2013). Building Integrated Photovoltaics (BIPV): Review, Potentials, Barriers and Myths. *Green*, 3(2), pp.125-156.
- Hoppmann, J., Volland, J., Schmidt, T.S., Hoffmann, V.H. (2014). The economic viability of battery storage for residential solar photovoltaic systems – A review and simulation model. *Renewable and Sustainable Energy Reviews*, 39, pp.1101-1118.
- IEA, (2002). *Potential for Building Integrated Photovoltaics, IEA report PVPS T7-4*. Switzerland.
- KBOB, (2016). Eco-building database. Available: [www.kbob.admin.ch](http://www.kbob.admin.ch) [15 March 2017].
- Luthander, R., Widén, J., Nilsson, D., Palm, J. (2015). Photovoltaic self-consumption in buildings: A review. *Applied Energy*, 142, pp.80-94.
- MB, (2017). Meyer Burger, *MegaSlate PV panels*. Available: [www.meyerburger.com](http://www.meyerburger.com) [15 Septembre 2017].
- Minergie, (2016). *Minergie standard certification*. Available: [www.minergie.ch](http://www.minergie.ch) [15 March 2017].
- NREL, (2003). *Guidelines for the Economic Evaluation of Building Integrated Photovoltaics Power Systems*. National Renewable Energy Laboratory. Colorado.
- OfS, (2015). *Statistical and census data 2015*. Neuchâtel.
- Rey E., Lufkin S., Ballif Ch., Wuestenhagen R., Wittkopf S., Bacher J.-P., (2015). *National Research Programmes NRP 70 «Energy Turnaround» and NRP 71 «Managing Energy Consumption»*, Kick-off Meeting, Luzern, Switzerland, April 24 2015.
- Riera Pérez M, Rey E., (2013). A multi-criteria approach to compare urban renewal scenarios for an existing neighbourhood. Case study in Lausanne (Switzerland). *Building and Environment*, 65, pp.58-70.
- SIA, (2011). *SIA 2040, La voie SIA vers l'efficacité énergétique*. SIA. Zurich.
- SIA, (2017). *SIA 380/1:2016, Besoin de chaleur pour le chauffage*. SIA. Zurich.
- Swiss-green, (2017). Solar batteries. Available: [www.swiss-green.ch](http://www.swiss-green.ch) [15 Septembre 2017]
- Swissgrid, (2017). *Promotion des énergies renouvelables*. Available: [www.swissgrid.ch](http://www.swissgrid.ch) [15 March 2017]
- Swissolar, (2017). *Installations PV avec batteries*. Available: [www.swissolar.ch](http://www.swissolar.ch) [15 March 2017]
- Vuarnoz, D., Jusselme, T., Cozza, S., Rey, E., Andersen, M., (2016). *Studying the dynamic relationship between energy supply carbon content and building energy demand*. In: 32nd International Conference on Passive and Low Energy Architecture, Los Angeles, USA, 11-13 July 2016.

# Building with Date Palm Rachis for the empowerment of rural communities in Egypt

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**Abstract:** Historically, builders in rural areas and oases depended on agricultural-based building materials to build fast and cheap houses. Therefore, the revival of the concept of Natural Building using agricultural based building materials rose as an international concept to develop poor societies from the inside. Building with natural materials encourages societies to build with their own hands using local materials such as timber and bamboo, which the communities are familiar with in the form of small projects and handmade households. This increases the sense of ownership and empowers poor rural communities by being the true stakeholders of their houses. This leads to decreasing the economic costs, environmental impacts and enforcement of the social structure and culture.

Therefore, traditional building materials such as Bamboo and timber have been the focal point of many of the previous research work that aim to revive and simplify their construction techniques to introduce them as potential building materials for rural communities instead of the full dependence on conventional building materials. However, the knowledge gap lies within the absence of an integrated and comprehensive analysis of the practicality of Date Palm Rachis, which is one of the most abundant and versatile agricultural residues in Egypt, and has been used for decorations, sheathing and furnishing in oases and rural communities in Egypt. This paper aims to analyse the potentials of using Date Palm Rachis for local, simple and cheap construction, based on a qualitative analysis and practical experience to assess abundance, workability and previous researches. This paper shows that Date Palm Rachis has high potentials for further research studies to increase the efficiency and flexibility of the structures which can satisfy the social need of cheap, fast and easy construction techniques by the hands of rural communities in Egypt.

**Keywords:** Date palm rachis, Empowerment, Rural communities, Cheap construction, vernacular architecture

## Introduction

Cost effective and environmentally appropriate materials and techniques are needed to be adopted to meet the increasing inflation globally and the increasing costs of conventional materials such as concrete and steel (Madurwar et al., 2012), which in the same time contribute directly to the decrease of the in order to decrease the high expenses of the construction process.

And in the same time, the disposal of agro-residues and other solid wastes are a serious environmental and health issue in the developing countries (Madurwar et al., 2012). Egypt generates around 82,000 tons daily of agro-residues, that are mostly burned as a cost effective solution for growers to clear their land quickly which cause environmental degradation, or dumped on the banks which threatens the water quality and causes serious health problems (Elshimi, 2005). Therefore, attention is gaining momentum on the utilization of agro-residues in cheap construction especially in agricultural countries (Pandy & Sungatha, 2003) where wood is not abundant enough to be used safely for construction instead of the conventional materials (Patel et al., 2013).

Agro-industrial field has developed lately to utilize the agro-residues in various purposes, which not only solves the shortage of waste management in developing countries, but also offer new products that are cheaper and more eco-friendly, as the agro-residues cut the large proportion of the costs of the raw materials, and their renewable nature that is independent of non-renewable resources make them more sustainable alternatives than the conventional imported raw materials (Patel et al., 2013). In Egypt, combusting for energy production and animal feed are the main fields that utilize agro-residues such as rice husks, rice straw and cotton stalks (Hussein & Sawan, 2010), in addition to the manufacturing of timber-like panels from Date Palm Rachis for floorings and furniture (Elmously, 2005). This familiarity with agro-residues originated from the traditional techniques of sheathing using reeds and Date Palm Rachis in the rural communities in the Nile Valley and the western oases as discussed later in this paper (Ahmed, 2014).

One of the most available examples of the familiarity between agro-residues and the rural communities in Egypt is utilizing Date Palm Rachis in handcrafts. The abundance of date Palm Trees in Egypt granted Date Palm Rachis its wide and old technical heritage in handmade arts, ornaments, baskets, crates and furniture as illustrated in Figures 1 and 2 (Elmously, 2001). Lately, Date Palm Rachis have been manufactured to produce industrialised strips that are gathered and pressurized to make floorings that are substitute to timber floorings as illustrated in Figure 3 (Elmously, 2001). However, these utilization techniques do not fully exploit the entire potentials of the material as structural elements which can help decrease the entire dependence on conventional building materials for building in the rural areas in Egypt.



Figure 1 Bread Crates Made from Date Palm (Hanafy, 2010)



Figure 2 Chairs made from date Palm Rachis in Egypt (Hanafy, 2010)



Figure 3 Date Palm Rachis manufactured strips (Zayed, 2013)

### Contemporary Architecture in Rural Egypt

Rural communities abandon traditional architecture and local materials for the sake of sophisticated, flexible and industrialized materials to cope with the modern life style. The lack of trust in the abilities of vernacular architecture and local materials to cope with the changes and demands of the modern life style; such as flexibility, simplicity and cost efficiency, introduced the conventional materials such as concrete and steel as the only choice in construction. Traditional houses in the Nile Valley and the western oases are being abandoned to deterioration or demolished, where the youth strive to adopt a modern lifestyle where they can live in industrialized and conventional materials houses, which due to the high expenses are being executed with poor quality that can be identified as unsafe structurally and unacceptable visually (Moustafa, 2014).

### *Attempts of Reviving Vernacular Architecture*



Previous experiments of reviving traditional architecture in the same original manner are respected, but are out-dated by the youth. Previous attempts to revive vernacular architecture had not shown the wanted results of extending through the rural communities in Egypt. Hassan Fathy's idea of mud brick construction that was inspired from Nubian architecture is mostly being used now for building for tourism and villas projects instead of being the ultimate solution for building dwellings for the poor. El Gournia village he designed and built is threatened now with deterioration under the overlooking of the government and inattentiveness of the community as illustrated in Figure 4, due to social, economic and functional reasons, which architecture cannot be parted from (Guitart, 2014).



Figure 4 Deterioration of ElGournia village

### ***Youth and Vernacular Architecture***

In depth previous researches showed that the youth in rural communities still value traditional mud brick houses for instance, but seek buildings that reflect the modern life style as illustrated in Figure 5, with structures that can cover larger spaces that the traditional structures with modern and sophisticated look for their houses, while exerting less physical efforts in building and maintenance. The constantly increasing rates of building with conventional building materials, such as concrete and steel, gradually decrease the area of the agricultural land because of the non-biodegradable wastes through the life cycle of the buildings in construction and demolition in spite of the governmental guidelines of construction waste management (Al-Ansary, 2004). However, this conventional construction method remains demanded as the high land value requires more flexible land distribution as in multi-story structures or movable structures (Dabaieh, 2013).



Figure 5 concrete and bricks building among the mud bricks houses (Dabaieh, 2011)

### ***Agro-residues for Adaptive Vernacular Architecture***

And by investigating previous trials in reviving construction using agro-residues in the developing countries, these trials are more focused on using these agro-residues such as bamboo and reeds to build flexible and multi-functional community centres and shading of recreational spaces, where the flexibility and the wide span of these structures demonstrate

their strength as a live advertisement, where rural communities, that are used to building with conventional building materials, can learn about the potentials of agro-residues as durable and efficient building materials (Kennedy, 2004). Meanwhile, there is a general misconception about agro-residues in Egypt, as wastes that can sometime be used for handmade crafts, but mostly, they are just wastes.

Figure 6 shows the developed use of Bamboo to build schools sports hall in Thailand (Chiangmai Life Construction), while Figure 7 shows the traditional building type of the Mudhif, that is used to host occasions and meeting in Iraq, completely made of reeds that is harvested from the marshlands of El Ahwar, Iraq (Almssad & Almusaed, 2015). Date Palm Rachis is used in the making of walls of the Arish Houses in United Arab Emirates as shown in Figure 8. (Piesik, 2012)



Figure 6 The Multi-purpose hall of Panyaden International School in Thailand (Chiangmai Life Construction)



Figure 7 Mudhif structure in Iraq (Sayigh, 2014)



Figure 8 Traditional Palm Trunk Roofing Centre Qattara heritage oasis (Piesik, 1012)

### ***Date Palm Rachis: Bamboo of Egypt***

Date Palm Rachis is one of the most important agro-residues in Egypt, occupying the highest percentage of the pruning residues of Date Palm trees, with over 30,000 tons annually all over the country (Elmously, 2003). Date Palm trees are found the western oases, along the northern coasts, along the Nile Valley and in Sinai. This abundance and the familiarity of utilizing Date Palm Rachis in handcrafts, as discussed earlier, require exploiting this familiarity to develop the potentials of Date Palm Rachis for complete construction. Therefore, it has to be introduced to the rural communities in a way that solves this shortage of shaded areas, which can demonstrate the construction potentials, the practical and structural abilities and durability of Date Palm Rachis for light and fast shade structures.

### **Objectives and Methodology**

The main objective of this paper is to introduce Date Palm Rachis as a promising building material that can contribute to reduction of the entire depending on conventional building materials in rural Egypt. This objective is achieved through the following methodology:

1. Comprehensive analysis of Date Palm Rachis: abundance, traditional building techniques, preparation and curing.
2. Practical Experience: a simple shade is constructed by the authors and local volunteering workers from El Qayat village in Upper Egypt, as of one of the most experienced villages in Date Palm Rachis utilization in furniture industry.

### **Comprehensive Analysis of Date Palm Rachis as Building Material**

The analysis is based on the factors to be considered before selecting material (Mehta et al., 2014) as the following:

### ***Abundance and Renewability***

Date Palm has been a part of the Egyptian culture since the age of the Ancient Egyptians (Hyams, 1977). There is no doubt that the strong technical heritage that is surviving now in the middle of manufacturing and plastics has roots that run deep to Ancient Egypt (Figure 9) and Coptic Egypt, where Date Palm Leaves imposed a great value in culture and religion (Darby et al., 1977 ). This technical heritage was born due to the abundance and spread of Date Palm Rachis along the country (Bekheet and Sharabasy, 2015).

Latest statistics show that the total number of productive Date Palm trees is about 14 million trees, making Egypt the second highest country in the world concerning production of Dates annually (Bekheet, 2015). Date Palm Trees are present in the cultivated areas of approximately 74 thousand Feddans which represents about 6.32% of the total fruit producing area in Egypt, producing around 13.91% of the total fruit production in Egypt and 20% of the total date production in the world (FAO 2002). Those areas are distributed over the Nile Delta, along the Nile Valley and Upper Egypt, in the New Valley and western oases, and in North and South Sinai (Raid, 1993).

Date Palms are required to be pruned annually to remove diseased tissues, and to stimulate and improve the quality of the dates production. The pruning residues vary from coir, petioles and leaves. After pruning, every date palm is sprayed of special insecticides that fight Red Palm Weevil (Bekheet, 2015).

A palm leaf consists of the rachis, which is the main axis that bears the dates, and the leaflets that grow at the edges of the rachis. Date Palm Rachis is the largest pruning residue from a tree, occupying 30% of the amounts of the Date Palm pruning residues. Every 8 rachises share in bearing of 1 date cluster that could weigh 8-12 kg (Zaid & de Wet, 1999). The length of Date Palm Rachis varies from 3 to 6 m depending on the variety and the surrounding conditions (Zaid & de Wet, 1999). Each tree produces 10-20 new leaves every year. The width of the Date Palm Rachis is the widest right at the triangular petiole base where it can reach 50cm, and decreases towards the end of the rachis to be a circular cross section with diameter of about 1cm dia. as illustrated in Figure 10.



Figure 9 Kneeling before a Date Palm Tree in the Book of the Dead (Magi, 2015)

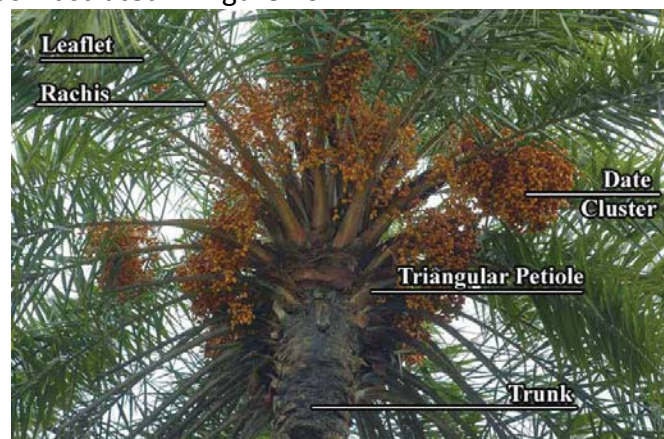


Figure 10 Date Palm Parts adapted from (*Britannica ImageQuest*, Encyclopædia Britannica, 25 May 2016. [quest.eb.com/search/300\\_3206131/1/300\\_3206131/cite](http://quest.eb.com/search/300_3206131/1/300_3206131/cite). Accessed 23 Aug 2017.)

### ***Recyclability and Traditional Building Utilizing Date Palm Rachis***



The main traditional technique of building using Date Palm Rachis in Egypt is basically threading. Date Palm Rachis is used to make threaded jalousies that build up the walls and roofs of small and temporary kiosks along the railways and waterways in Upper Egypt as illustrated in Figure 11 (Elmously, 2001). Those jalousies are planted in the soil and tied by linen ropes to columns and beams that are palm stems or tree branches or imported wooden bars as illustrated in Figure 12, and the roofs are cross layers of Date Palm Rachis to oppose the direct sun radiation and unexpected rain. Those jalousies can be reused to make threaded mats for cowshed and animal yards. In Siwa and the western oases in Egypt, threaded mats of Date Palm Rachis are tied to olive tree stems or palm trunks to make sheathing of internal ceilings as shown in Figure 13 (Ahmed 2014).



Figure 11 Temporary Kiosks in Upper Egypt



Figure 12 Timber Post-Beam shades (Hanafy, 2010)

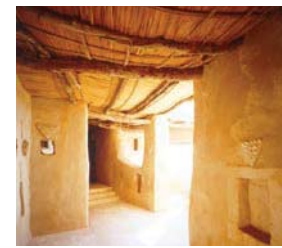


Figure 13 Jalousies of Date Palm rachis for roofing in Siwa (Ahmed, 2014)

Moreover, fibers of Date Palm Rachis are used in many recyclable applications such as particleboards, block-boards and lumber-like products as substitute for imported wood. In addition, the fibers are used in the manufacture of bio-composites as substitute for thermal insulation and fiberglass (Elmously, 2001).

### ***Durability and Preparation of Date Palm Rachis***

The first step of the preparation of Date Palm Rachis after the pruning is to take off the leaflets after 1 day of the pruning. Then the rachis is put in the dry air in sunny areas to initiate the drying process.

Rachises are dried to approximately 12% moisture content in order to increase the stiffness and resilience of the elements before using them (Piesik, 2012). The natural bent shape remains in the Date Palm Rachis even after drying, where the longest straight portion of Date Palm Rachis does not exceed 2 m in length (Zaid and de Wet, 1999). This depends mainly on the age, species and the drying method used. Based on the personal notice; the traditional drying methods vary between the following:

1. Horizontal Drying: when the rachises are to be used for straight shapes such as fences, shades and crates, the elements are put horizontally on the ground to decrease the natural curvature as most as possible. However, due to the moisturizing vapour occurring in between the horizontal layers, the drying process can extend to almost 3 months, as shown in Figure 14.
2. Vertical Drying: when the rachises are to be used for making furniture which can make use of the natural curvature, the elements are put vertically supported by a wall. Thus, the drying process takes only 1 month as all the members are exposed to direct sunlight without the vapour effect. However, the members sustain their natural curvature, which may increase according to the supporting angle, as shown in Figure 15.



Figure 14 Horizontal Drying of Date Palm Rachis



Figure 15 Vertical Drying of Date Palm Rachis

### ***Mechanical Properties***

A Date Palm Rachis consists of dense longitudinal bundles of fibers. This density decreases radially from  $1.14 \text{ gm/cm}^3$  at the outer layer down to  $0.8 \text{ gm/cm}^3$  at the core (Elmously, 2005). Therefore, it is advised to use whole Date Palm Rachis in construction, to make use of the high density of the fibers which increases the strength of the members (Elmously, 2005). The mechanical properties of the whole Date Palm Rachis, Baladi Species from the Nile Valley, were measured and were found as the following in Table 1.

Table 1 Mechanical Properties of Whole Date Palm Rachis ( Mansour et al., 2017)

Property Description	Value
Longitudinal Modulus of Elasticity $-E_L$	10287.8 MPa
Tangential Modulus of Elasticity $-E_T$	105.45 MPa
Radial Modulus of Elasticity $-E_R$	105.45 MPa
Longitudinal-Radial Poisson's Ratio $-V_{LR}$	0.372
Longitudinal-Tangential Poisson's Ratio $-V_{LT}$	0.467
Radial-Tangential Poisson's Ratio $-V_{RT}$	0.435
Longitudinal-Radial Shear Modulus $-G_{LR}$	109.2 MPa
Longitudinal-Tangential Shear Modulus $-G_{LT}$	109.2 MPa
Radial-Tangential Shear Modulus $-G_{RT}$	39.05 MPa
Mass per Unit Volume	$0.95 \text{ gm/cm}^3$
Effective Yield Stress	45 MPa
Effective Tensile Stress	54 MPa

The mechanical properties of whole Date Palm Rachis were found to be competitive to spruce wood, which is one of the most imported timber in Egypt (Elmously, 2001).

### ***Environmental Impact***

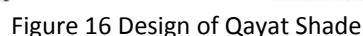
So far, no studies have illustrated the exact values of the embodied energy, embodied carbon, thermal properties and fire resistance. The closest assumption of the environmental assessment can be predicted to be close to that of reeds. Long reeds grow naturally on the marginal lands and require treatment or annual pruning to sustain the quality of the crops (Magwood, 2014). Reeds are often used in traditional sheathing and roof thatching in Southern America, depending on low to no machinery, and minimal processing that includes no more than cutting, cleaning and bundling (Magwood, 2014). These facts validate the assumption of the relative resemblance between the environmental assessment values of reeds and date palm rachis, where the embodied energy equals  $0.24 \text{ Mj/Kg}$ , and the embodied Carbon equals  $0.01 \text{ kgCO}_2/\text{Kg}$  (Magwood, 2014).



## Practical Experiment: Simple Shade in Qayat Village

Therefore, it was decided that if a simple shade of Date Palm Rachis was built by the locals in short time with the least possible costs, it would be the most effective way of showing the true potentials of Date Palm Rachis, which would invite more builders and social worker to further investigate the power of Date Palm Rachis in construction.

The location of the proposed shade was in front of an old date palm rachis drying facility, as a rest area for the workers. And in order to finish the shade in the shortest time, the area of the shade was designed to be only 3x2m. The shade was designed to be Post and beam structure using Rachis bundles, with a cantilever inclined sun breaker towards the southern orientation as illustrated in Figure 16. The columns and beams were designed to be made of rachis bundles, which is the popular way of collecting and drying the rachis vertically as illustrated previously in Figure 15. Although the authors put the primary design of the shade, all the details of the members and the joints and the procedures of building the shade were suggested by the locals depending on their experience as crate and furniture worker.



### ***Building the Shade***

The rachis members used for horizontally dried (figure 17), and the curved petioles were trimmed to help increase the average straightness of the members (Figure 18). The fibers of the trimmed petioles can be used in the production of bio composites (Elmously, 2001).



Figure 17 Dried Date Palm Rachis



Figure 18 Trimming the Petioles

Then, the members are cut to the needed lengths (Figure 19) and bundled using plastic ties vertically to ensure the length of the bundles (Figure 20). The plastic ties were used they could be fastened easier, and then linen robes were used to protect the plastic ties from the direct sunlight above the ground (Figure 21). The plastic ties were left without the linen rope in the parts of the bundles that were to be planted underground at the depth of 30cm, as the linen ropes would not resist the humidity in the soil.



Figure 19 Cutting the element to the needed lengths



Figure 20 Tying the bundle vertically to check the length



Figure 21 Tying the Linen Rope over the plastic ties in the bundles

At specific points where the columns were to be planted, the soil was humidified until it had clay like texture, and the columns were planted in holes with the depth of 30cm. The holes were filled with the soil and pressurized by hand as illustrated in Figure 22. After planting the 4 columns, upper, intermediate and lower beams were tied to the columns (Figure23).



Figure 22 Planted column in the wet soil



Figure 23 Tying the beams to the columns



The rachis lattice are added to increase the stiffness of the shade and tied to the columns and beams using plastic ties and linen ropes as illustrated in Figures 24 and 25. In addition, 2 diagonal bracings were added in the ceiling of the shade as illustrated in Figure 25.



Figure 24 Fixing the horizontal lattice members



Figure 25 Fixing the vertical lattice members

For the cantilever sun breaker, 2 inclined supporters were fixed on the 2 columns as illustrated in Figure 26. Then, the supports were linked with a secondary beam. This secondary beam was found to suffer deflection. Therefore, intermediate supporters were fixed to the main beam to carry the beam of the sun breaker as illustrated in Figure 27.



Figure 26 The fixation of the inclined supporters to the column



Figure 27 The intermediate supporters to carry the sun breaker beam

Additional vertical supporters were added to reduce the deflection of the intermediate beam in the back elevation as illustrated in Figure 28. Finally the joints are rechecked by tying a continuous linen rope all over the structural system as illustrated in Figure 29.

After the completion of the shade (Figure 30), the following points were noticed:



Figure 28 Adding the vertical supporters to decrease the deformation of the intermediate back beam



Figure 29 Tying the continuous linen rope all over the structure

Upon the completion of the shade (Figure 30), the following points were noticed:

1. The shade that was built based on the local experiences showed that due to the natural bent shape of Date Palm Rachis, deformation occurred in the beams, especially in the cantilever sun breaker beam which suffered major deformation even with the help of the intermediate supporters.
2. In addition, the impact of climatic conditions such as humidity or wind would decrease the stability of the joints due to the full dependence on ropes or would cause erosion of the ropes and the plastic ties beneath.



Figure 30 The final shade after completion

## Conclusion

Date Palm Rachis is a promising material as one of the most abundant pruning residues in Egypt which enjoys high familiarity in using for handmade crafts such as crates, ornaments and furniture in the rural communities in Egypt. Although Post-Beam structures prove to be unsuitable for the natural bent shape of Date Palm Rachis, the shade demonstrated the high potential of the material for simple and light construction, in addition to manifesting the high acceptance of the locals towards the shade due to its simplicity and cheapness, as the local workers felt proud of their work and the more workers volunteered to complete the shade and watch the building procedures to build their shades afterwards.

## Recommendation

The findings of this paper call for further investigations in the public acceptance towards Date Palm Rachis as a building material, in addition to further researches to improve the traditional building techniques of Date Palm rachis in Egypt to be introduced for light and cheap structures that fit the modern lifestyle of the youth in rural communities.

## References

Ahmed, R. (2014). Lessons Learnt from the Vernacular Architecture of Bedouins in Siwa Oasis, Egypt, In: *The 31st International Symposium on Automation and Robotics in Construction and Mining* (London, UK: ISARC, 2014).

- Al-Ansary, M.; El-Haggar, S. and Taha, M., (2004). Sustainable Guidelines for Managing Demolition Waste in Egypt. In : *International RILEM Conference on the "Use of Recycled Materials in Buildings and Structures*, Barcelona, Spain, Nov 2004, RILEM: Barcelona Forum
- Almssad, A. and Almusaed, A. (2015). Building materials in eco-energy houses from Iraq and Iran, *Case Studies in Construction Materials*, 2, pp. 42-54.
- Bekheit, H. (2015). Date Palm Good Practice in Egypt, Cairo, Egypt:FAO.
- Bekheet, S. and El-Sharabasy, S.(2015). Date Palm Status and Perspective in Egypt, Al-Khayri, J et al. Date Palm Genetic Resources and Utilization:Volume 1: Africa and the Americas, UK: Springer, pp.75-124.
- Dabaieh, M. (2013). Participatory action research as a tool in solving desert vernacular architecture problems in the Western Desert of Egypt, *Action Research*, 11(3), pp.279–298
- Darby, JW.; Ghalioungi, P. and Louis, G. (1977) .Food: the gift of Osiris, vol 2. London, UK: Academic
- Hyams, E. (1971) A history of gardens and gardening. New York, US: Praeger
- Elmously, H. (2001). THE INDUSTRIAL USE OF THE DATE PALM RESIDUES: AN ELOQUENT EXAMPLE OF SUSTAINABLE DEVELOPMENT, In: 2nd Inter. Conf. on Date Palms. March 25-27, Al-Ain, United Arab Emirates Univ., pp. 866-886
- ElMously, H. (2005). The Palm Fibers for the Reinforcement of Polymer Composites: Prospects and Challenges', In: *The First Ain Shams International Conference on Environmental Engineering* (Cairo, Egypt: Ain Shams University, 2005), pp. 746-76.
- El-Shimi, S. (2005), *Design and Cost Analysis of Agricultural Waste Recycling Alternatives for Sinbo Village*, Gharbiya Governorate, International Resources Group Ministry of Water Resources and Irrigation , Cairo: USAID
- FAO (2002) *Date palm cultivation*. Rev. 1. , Rome, Italy: F AO
- Guitart, M. (2014). The Failed Utopia of a Modern African Vernacular: Hassan Fathy in New Gourn, *Journal of Architectural Education*, 68 (2), pp166-177.
- Hanafy, Abdelwahab, 2010, Date Palm Rachis: craftworks, Arabic Ed., <http://kenanaonline.com/users/saharyfolk/posts/222714>, last accessed August 2017
- Hussein, S and Sawan, O.(2010). The Utilization of Agricultural Waste as One of the Environmental Issues in Egypt (A Case Study), *Journal of Applied Sciences Research*, 6 (8).pp.1116-24
- Kennedy, J. (2004). *Building without Borders*, Gabriola, Canada :New Society Publishers.Magi, G. (2015), *Art and History of Luxor: Karnak: The Valley of the Kings* (Bonechi Art and History Series, Florence, Italy: Casa Editrice Bonechi.
- Mansour, Y.; Elmously, H. and Darwish, E.(2017), Utilization of Date Palm Rachis for Fast and Eco-friendly Construction in Egypt, In : *World Sustainable Built Environment*, Hong Kong, 5-7 June, 2017, Hong Kong: Hong Kong Green Building Council, pp.2824-2832.
- Magwood, C. (2014) *Building Better Buildings: A Comparative Guide to Sustainable Construction*, Gabriola Island, Canada: New Society Publishers.
- Madrurwar, M. et al (2012) Application of Agro-Waste for Sustainable Construction Materials. In: *Construction and Building Material 38<sup>th</sup> Conference*, Nagpur, India, Dec 2012, Elsevier.
- Moustafa, W.(2014). Vernacular Architecture Approach to achieve sustainability in Informal Settlements, In: *World Sustainable Built Environment*, Barcelona, Spain, 28-30 Oct. 2014, pp.200-7
- Panyaden International School Sports Hall, Chiangmai Life Construction, <https://www.bamboo-earth-architecture-construction.com/portfolio-item/panyaden-international-school-sports-hall/>, last accessed August 2017.
- Pandey, C. N., & Sujatha, D. (2011). Crop residues, the alternate raw materials of tomorrow for the preparation of composite board. *Indian Plywood Industries Research & Training Institute*.
- Patel, A.; Salla, S., Pitroda, J.(2013). A Study on Utilization of Agro-Wastes as and Innovative Material in Indian Context, *International Journal of Scientific Research*, 2 (2), pp. 119-24
- Piesk, S. (2010). *Arish: Palm Leaf Architecture*, London, UK: Thames and Hudson
- Riad, M. (1993) The date palm sector in Egypt. In : Ferry M. (ed.), Greiner D. (ed.). *Le palmier dattier dans l'agriculture d'oasis des pays méditerranéens*. Zaragoza : CIHEAM, 1993. p. 45-53 (Options Méditerranéennes : Série A. Séminaires Méditerranéens; n. 28)
- Sayigh, A. (2014). *Sustainability, Energy and Architecture:Case Studies in Realizing Green Buildings*, 2nd edn, Massacusetts, US: Elsevier Publishers
- Zaid, A. and De Wet, P. (1999). Chapter I botanical and systematic description of date palm, in *FAO plant production and protection papers*, 1999, pp.1–28, <http://www.fao.org/docrep/006/y4360e/y4360e05.htm>, last accessed Aug.2017



# Water-Efficient Construction Practices for Housing Projects in Egypt: A Review of Literature

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**Abstract:** Egypt currently faces high housing demands and water stress issues due mainly to its large population, with further problems resulting from Climate Change and a per capita share predicted to reach “absolute water scarcity” in 2025. The construction of housing projects utilizes great quantities of water through both the off-site and on-site practices.

This paper firstly outlines the scope and methodology of Life Cycle Assessment (LCA) for buildings, reviewing previous literature of water demand and footprint for housing construction. The paper discusses also the local Egyptian regulations for green buildings in terms of water efficiency and the use of building materials. The aim is to highlight the significant water footprint of housing construction, stating recommendations for further building assessment, development and research.

The paper highlights the importance of using LCAs for pre-design decision making to achieve the sustainability of construction industry, overcoming resource depletion. While the direct water demand was mostly concerned in previous literature, the review proves that the embodied water of construction practices is significantly higher than other lifecycle phases of various housing projects. The paper also shows that Egypt lacks LCA studies of water use in residential buildings despite having vast deserts and limited water resources for future expansion.

**Keywords:** water efficiency, water footprint, construction phase, housing, Egypt

## Introduction

Egypt is ranked number four among the world's highly water stressed countries (Anon., 2011), where low water availability currently limits its national urban growth. Population predictions will lower Egypt's per capita share to less than 300 m<sup>3</sup>/capita/year in 2050 (Kobayashi, 2011), below the 'absolute water scarcity' limit of 500 m<sup>3</sup>/capita/year (Falkenmark, 1989).

It is estimated that the built environment globally consumes 20% of water (Huovila and Branch, 2007) and that green buildings can reduce usage by almost 40% (McGrow-Hill Construction, 2008). Housing is primarily considered a basic human necessity and a major lifetime investment, beside being related to 7% of global jobs and 10% of the global GDP (Arimah *et al.*, 2009). Housing is also greatly responsible for the GHG emissions, energy use, resource depletion, waste production, and changing of land-uses.

The fundamental driver of housing markets is basically their annual household formation rates determined by population growth and age structure. The population of urban areas in Egypt is forecasted to surpass that of rural areas, beside an overall expected population exceeding 120 million in 2050 (UN DESA, 2014). According to 2015 statistics shown, Egypt reached a population of 88.96 million with an age profile percentage of 61.8% for ages between 15 and 59 (CAPMAS, 2016). This combination of factors is driving the increased housing demand across the Egyptian market.

### ***Climate Change impact***

The natural Nile flow is greatly sensitive to rainfall and temperature changes, where some studies suggest a spacing in the rainfall periods with a rise in heavy rainfall rates that causes more extreme cycles of floods and droughts annually. The economic development and adaptation programs to such climate changes in upstream riparian countries would probably put more stress on the water resources of Egypt. In addition, the forecasted rise of sea levels will increase the salinity of Delta aquifers, decreasing their validity for use.

Housing demand is subjected to increase suddenly due to possible mass migrations from rural to urban communities caused by strong and frequent floods, droughts, desertification and also rise of sea levels (Dahou *et al.*, 2012)(Stanley and Clemente, 2017). Moreover, residents of slums are highly vulnerable to strong heat waves and severe rainfall rates, in addition to communities prone to floods along rainfall streams. Such migrations would drastically demand more urgent housing units to be constructed with limited resources.

### ***Key housing challenges***

The 'conquest of the desert' concept was based mainly on the optimum exploitation of vast deserts to evenly distribute the population throughout Egypt. Some issues are considered crucial challenges for housing expansion (Wallbaum *et al.*, 2012), including:

#### ***Scarcity of resources***

The consumption of natural resources increases tremendously by the accelerating urban expansion. This challenge means to seek improving existing methods and innovative technologies for resource substitution or efficiency. For housing construction, this means delivering high quality building materials, boosting its resource efficiency and performance.

#### ***Wastage due to inefficiency***

The resource wastage caused by an inefficient tool or process raises the investment costs and negatively impacts the consumption of resources, requiring higher efficiency standards of material flows with a shift to prefabrication.

### **Green construction assessment tools**

There are diverse green construction methods and technologies that differ by region and that are constantly developing. No matter how they are combined, the core of green construction should optimize one or some of the key principles: the efficiency of siting and design; the usage efficiency of energy, water and raw-materials; the enhancement of indoor quality; the optimization of building operation and frequent maintenance; beside waste reduction.

### ***Life Cycle Assessment***

LCAs are tools for systematically analysing the life-long environmental performance intended for products, covering raw material processing, product manufacture, recurrent use and either disposal, reuse or recycling at last (Cabeza *et al.*, 2014). The specification of LCAs depends primarily on the International ISO 14040 standard series, comprising four analytical steps: scope and goal definition, inventory creation, impacts assessment and results interpretation. Various construction-related databases and tools can provide standardized inventory data and assessment models in a three-hierarchical classification as followed:

1. Database tools for product comparison like SimaPro, BEES and GaBi.
2. Support tools for whole-building decisions like Envest 2 and Athena Eco-Calculator.
3. Assessment frameworks and systems for whole buildings like LEED and BRE systems.

The scope of LCA studies varies: “Cradle to Gate” studies include the full raw-material processing, transportation and manufacture of a building component. “Cradle to Site” studies additionally consider the transportation to and installation on site. Further “Cradle to Grave” studies include recurrent maintenance and later disposal. And finally, “Cradle to Cradle” studies cover closed-loop cases of products recycled.

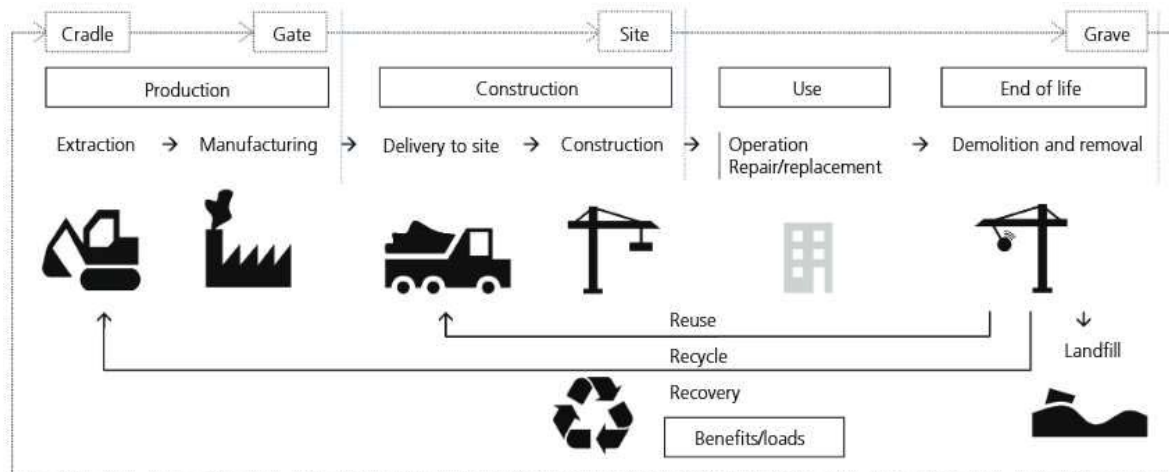


Figure 1. Different assessment scopes of LCA studies (Clark, 2013)

### **Environmental Product Declaration (EPD)**

EPDs demonstrate the environmental specifications from broader LCA studies using a standardized format, according to rules known globally as Product Category Rules. A Program Operator such as BRE Global, EPD Norge or IBU publishes EPDs using ISO 14025 compliant PCR (Anderson and Thornback, 2012).

Construction EPDs are so modular that EPDs of concrete, for instance, can be basically reached by combining EPDs of cement and aggregates. It is recommended for a manufacturer who produces a single product for different regions to produce separate EPDs for targeted regions. EPDs with same PCRs can be comparable, ensuring the similarity of data quality, methodology, scope and indicators. Due mainly to the variations in PCRs, they should all come from one EPD program. Moreover, products assessed are not comparable until having the same functional application and unit.

### **Water demand in residential buildings**

Much effort to enhance water efficiency and lower its demand in buildings focused on the water directly consumed by occupants, including the usage of efficient appliances. Such measures have greatly reduced water usage, although direct water consumption within buildings represents only one portion of the entire water demand, estimated at 12% globally (GBCA, 2006). Water is needed during the building construction as well, which includes the acquisition of raw-materials, the manufacturing of products and the supporting services, being known as indirect water.

Embodied water is referred to as the overall water needed to create and deliver a product during all production stages, including direct and indirect demands. Direct water is that water needed to mainly manufacture a specific product, while indirect water is that water specifically needed to process all the resources and raw-materials that go through the main product. Indirect water is basically harder to assign for any product due to the numerous forms of consumption possibly involved.

Table 1. Summary of literature reviewed by the researcher for residential case studies

Literature reviewed	Country (UN)	Cases (No.)	Lifespan (years)	Environmental impact			Life-cycle phases		
				G/C	E	W	Co	Op	EOL
(Blanchard and Reppe, 1998)	USA	2	50	●	●		✓	✓	✓
(Adalberth, Almgren and Petersen, 2001)	SWE	4	50	●	●		✓	✓	✓
(Chen, Burnett and Chau, 2001)	CHN	2	40		●		✓		✓
(Peuportier, 2001)	FRA	3		●	●	●	✓	✓	✓
(Mithraratne and Vale, 2004)	NZL	3	100		●		✓	✓	✓
(Thormark, 2006)	SWE	1	50		●		✓	✓	✓
(Gerilla, Teknomo and Hokao, 2007)	JPN	2	35	●			✓	✓	✓
(De Meester <i>et al.</i> , 2009)	BEL	65	75		●		✓	✓	✓
(Blengini and Di Carlo, 2010)	ITA	2	70	●	●		✓	✓	✓
(Ortiz, Castells and Sonnemann, 2010)	ESP & COL	2	50	●	●		✓	✓	✓
(Crawford and Pullen, 2011)	AUS	1	50			●	✓	✓	
(Carre, 2011)	AUS	15	50	●	●	●	✓	✓	✓
(Cuéllar-Franca and Azapagic, 2012)	GBR	3	50	●			✓	✓	✓
(Rossi <i>et al.</i> , 2012)	BEL	2	50	●	●		✓	✓	✓
(Basbagill <i>et al.</i> , 2013)	USA	1	30	●	●		✓	✓	
(Stephan and Crawford, 2014)	AUS	1	50			●	✓	✓	
(Oyarzo and Peuportier, 2014)	CHL	4	30-100	●	●	●	✓	✓	✓
(Ali <i>et al.</i> , 2015)	EGY	1	60	●	●		✓	✓	✓
(Islam, Jollands and Setunge, 2015)	AUS	1	50	●	●	●	✓	✓	✓

Environmental impacts:

G/C: Global Warming or Carbon Footprint

E: Energy usage

W: Water demand

Life-cycle phases:

Co: Construction

Op: Operation

EOL: End of life

Most studies concerning the environmental building performance concentrate on energy demand and associated emissions, often neglecting to consider the demands of other crucial resources with associated impacts, including water. Table 1 comparatively summarizes the literatures reviewed shows locations, numbers and lifespans of the assessed residential case studies beside the environmental impacts and lifecycle phases assessed.

### ***Water usage weights along building lifecycle***

Many studies that evaluate water demand of buildings only consider the operational water, excluding the embodied water (Stephan and Crawford, 2014). Figure 2 graphically shows the water consumption weights for buildings per lifecycle phase in two studies. A first case study conducted by Islam, Jollands and Setunge resulted in water usage outcomes of 62.6%, 35.2%, 2.11% and 0.01% for construction, maintenance, operation and EOL respectively (Islam, Jollands and Setunge, 2015). Another 15 case studies assessed by Carre reached 124%, 27.33%, 1.67% and -53.13% for the same assessed phases respectively (Carre, 2011).

This shows that the many studies focusing on the water use during operation only may fail to accurately identify the most optimum solutions for effectively improving the water efficiency of any building, highlighting the significant impact of water efficiency during building construction. Many parameters, including locality, climate, technology, methods of specification and analysis, can contribute to considerable variability in embodied water data.

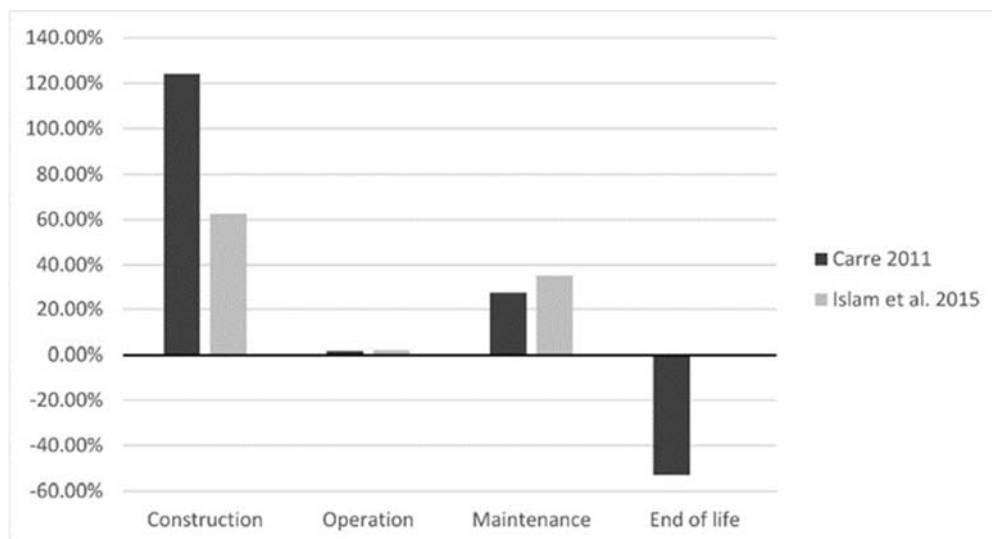


Figure 2. Water consumption weights of assessed case studies per lifecycle phase

### ***Analytical approaches for embodied water***

Process, input-output and hybrid approaches are primarily applied to analyse and quantify embodied water (Stephan and Crawford, 2014). Process analysis tends to trim the system boundary of a product, sometimes omitting crucial processes, causing the underestimation of total environmental impacts. Input-output analysis makes an average figure that relies on the disaggregation level of all input-output matrices representing the economy, causing high uncertainty levels that can counterbalance the merits of broad system boundaries.

Studies of Crawford, Suh and Dixit stated that hybrid analysis reaches more comprehensive, accurate and reliable end results by using process data (Crawford and Stephan, 2013), (Dixit, Culp and Fernandez-Solis, 2013), (Suh *et al.*, 2004). By combining both input-output and process analytical data, it includes the full system boundary. Therefore, hybrid analysis is superior to both techniques.



### ***Calculation schemes***

A research reported by Carre used a LCA methodology, based primarily on the 2006 ISO-14040 series, to compare the building construction types. Specific methods to develop inventory data for building material quantities and energy consumption over the life of the building were also used. The report discussed the LCI of building materials based on a “cradle to grave” analytical approach, including elementary flows, with some validation issues covered. The report reached a LCI assessment for building materials in some Australian case studies based on their space areas, B.O.Q.s and proposed 5-star rated design alternatives (Carre, 2011).

Another research by Bribián, Capilla, and Usón compared some conventional building materials with some alternative eco-materials according to three impact categories, using SimaPro v7.1.8 (Bribián, I. Z.; Capilla, A. V., Usón, 2011). The paper evaluated various materials, analysing their improvement possibilities and providing guidelines for material selection. The resulted demands can be basically used along with the densities of studied materials to estimate the total water demand of buildings using the B.O.Q.s of case studies.

In a study by Crawford and Pullen, the concluded embodied water of the case studied was estimated based on the manufacturing demands of building materials, using SimaPro Australian database (Crawford and Pullen, 2011). The I-O data were afterwards used to mainly fill in the missing gaps of upstream data for the materials. This resulted in hybrid coefficients of the embodied water of all the studied materials. Actual amounts of materials studied were collected individually from the B.O.Q. for the assessed house. These quantities were then individually multiplied by the respective coefficients of embodied water to reach the initial construction embodied water of the house.

Another study by Stephan and Crawford presented a developed framework with the equations necessary for the quantification of each water demand, covering uncertainty, computation and variability aspects (Stephan and Crawford, 2014). The paper reached a calculation method for embodied demands using coefficients for uncertainty and building materials. The life cycle water demand of the assessed case study included embodied water, operational water and transport water, categorizing embodied water demands into:

- Initial embodied water represented the sum of embodied water content for material acquisition, manufacture, transportation and construction.
- Recurrent embodied water represented the embodied water necessary to produce and replace materials during building operation.

### ***Uncertainty of results***

Investigating uncertainties of LCIs may include: the variability and random errors of figures describing inputs and outputs, the appropriateness of data, model uncertainty and finally neglecting important flows. The first type, due to specific process variations, measurement uncertainties or temporal variations as examples, is inherent to each practical process, with indicators of data quality sufficiently obtainable, however Blengini and Di Carlo was the only study to include this type (Blengini and Di Carlo, 2010). The other mentioned types of uncertainties are hard to estimate and should be reduced in impact by gathering more additional and precise data.

### ***Selection of functional units***

Cuéllar-Franca and Azapagic investigated the influence of choosing functional units, either the entire buildings or the net floor areas. The study however compared three residential alternatives with typical sizes and characteristics. When considering the "impact per square

meter" as a unified functional unit for comparisons, the detached house had the lowest impacts per unit floor area (Cuéllar-Franca and Azapagic, 2012). This was due basically to some impacts mainly associated with the size of household, including water and energy demand. When considering the "impact per occupant" however, the terraced alternative, the most compact case study assessed, had the lowest impact.

### ***Regional variations***

The universal nature of LCA studies combined with local chains of production makes comparisons more difficult. The regional shares of electricity, for example, greatly influences the operational impact. The study of Ortiz, Castells and Sonnemann compared a house in Spain with another in Colombia. In the study, about 20% of the energy totally required was covered by using electricity, with significant differences in production between both countries. The environmental load associated with electricity production in Spain was twice larger than in Colombia for most impact categories (Ortiz, Castells and Sonnemann, 2010).

### ***Transportation impact***

A frequent conclusion was the minor impacts induced by the transportation of building materials during construction. Most literatures reviewed by the researcher included this process. But as the materials used were often locally manufactured, the overall travel distances and impacts associated were limited, reaching sometimes 1% or less (Adalberth, Almgren and Petersen, 2001). Designers and administrators, who collaborated in the study by Blengini and Di Carlo, were surprised at the minor contributions of material transportation to far destinations (Blengini and Di Carlo, 2010). Table 2 shows the water demands for some land and overseas transportation types per 1 metric ton of load.

Table 2. Water demands per 1 metric ton of transportation load (Bribián, I. Z.; Capilla, A. V., Usón, 2011)

Impact category	Lorry, road	Freight rail	Transoceanic freight ship
Water demand (l/km)	1.466	1.115	0.097

### ***Reuse strategies***

In his study, Thormark mainly focused on the recycling potentials and the "Design for disassembly" concept, while Blengini and Di Carlo examined the demolition of a flat to basically verify their literature data. Both studies demonstrated the advantages of reuse, yet they had reservations concerning its feasibility on a large scale as it demands major changes in current practice (Blengini and Di Carlo, 2010) (Thormark, 2006).

### ***Water efficiency issues in green building regulations***

In response to Egypt's need for a green rating system, the Housing and Building National Research Center has accordingly introduced the Green Pyramid Rating System, aiming to:

- Provide a local benchmark for good performance of buildings in Egypt, being rated for their green qualifications through a credible system for rating.
- Enable designers, constructors and also developers to base their reasoned decisions on the environmentally intended impacts for local buildings.
- Encourage the sustainable design, construction and recurrent maintenance of buildings, nationally promoting green buildings.

The rating system includes seven categories that in turn comprise sub-categories. Credit points are awarded based on given criteria, and in specific cases further credit points cannot be attainable with none of the Mandatory Minimum Requirements included, as one requirement or more, in the same rating category (HBRC and EGBC, 2011). Unlike LEED and BREEAM rating systems, water efficiency has the largest category weight in GPRS as charted in Figure 3. This is an evident indicator to the critical importance of water efficiency measurements needed in Egypt, which faces high water stress.

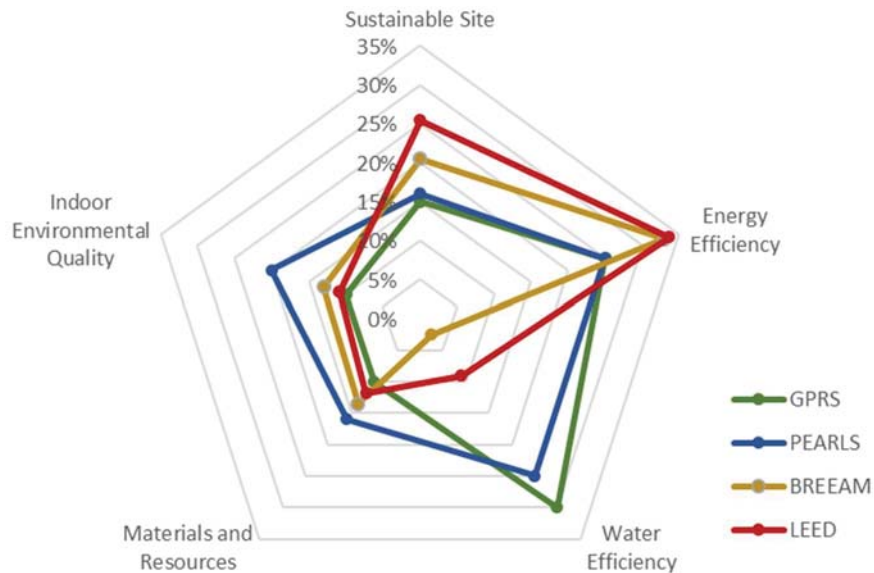


Figure 3. Comparing category weights of GPRS, PEARLS, BREEAM and LEED systems

### ***Issues in 'Materials and Resources' category***

The detailed description of the 'Regionally procured materials' requirement in 'Materials and Resources' category is: "Credit points are obtainable for demonstrating that building materials are extracted and manufactured in Egypt. Points awarded as follows: value of regional materials is not less than 25% of total materials value; value of regional materials is not less than 50% of total materials value; value of regional materials is not less than 75% of total materials value" (HBRC and EGBC, 2011). This description cannot be a comprehensive rating criterion because transportation distances and types are not mentioned nor evaluated. Different transportation loads for water consumption were previously figured in Table 2.

Similarly, the mentioned description of the 'Materials fabricated on site' requirement in 'Materials and Resources' category is: "A credit point is obtainable for demonstrating the use of building materials (such as bricks) that are fabricated on site" (HBRC and EGBC, 2011). This description cannot be a comprehensive rating criterion because resource control during on-site fabrication is not evaluated. However, the pre-fabrication of building components has been proved to be better in the terms of resource control and quality.

### ***Issues in 'Water Efficiency' category***

Although the construction process is a large water-consumer, the 'Efficient water use during construction' requirement has the lowest credit as comparatively figured to other sub-categories in Table 3. Moreover, its detailed description mentioned is "Credit points are obtainable for demonstrating the use materials such as pre-mixed concrete for preventing loss during mixing" (HBRC and EGBC, 2011). This description cannot be a comprehensive criterion concerning the total water embodied in building materials.

Table 3. Credit points in 'Water Efficiency' category (HBRC and EGBC, 2011)

Mandatory Minimum Requirements	
Minimum water efficiency	M
Water use monitoring	M
Additional Requirements	Maximum Credits
Indoor water efficiency improvement	8
Outdoor water efficiency improvement	9
Efficiency of Water-based Cooling	4
Water feature efficiency	4
Water leakage detection	6
Efficient water use during construction	3
Waste water management	12
Sanitary used pipes	4

## Conclusion

Egypt is ranked as a country with extreme water stress, being predicted to face a more severe shortage due mainly to the accelerating Climate Change and population in the future. Beside the housing growth due basically to the accelerated population, the housing demand is subjected to rise due mainly to the possible mass migrations caused by strong floods, droughts, desertification and rise of sea levels, including millions in northern Delta. Resource scarcity and waste caused by inefficiency are key housing challenges. With the current stress on existing cities, the 'conquest of the desert' concept has been based on the optimum exploitation of Egypt's vast deserts to evenly distribute its population.

The major indicators of any sustainable development, concerning the society, economy and environment, call great attention to construction industry emerging. LCAs should be used for supporting decision making to primarily reach a sustainable industry, overcoming resource depletion and other issues. Concerns about using different goals, scopes and methodologies, confidentiality of detailed data on manufacturing and size of reports, which can make LCAs unwieldy for communication, mean that construction industry should adopt EPDs.

Most previous studies of reducing water demand have continually focused on direct water usage. However, water is indeed consumed during the processing, manufacturing and installation of building components and systems. Many parameters, including locality, climate, technology, methods of specification and analysis, can contribute to considerable variability in embodied water data. System boundaries typically induce significant diversity between LCAs of a similar topic, however the wide boundaries considered appeared consistent. Many studies regarded the entire buildings as functional units, but with remarkable variations in properties, size, location, impact ...etc, achieving indirect comparable results. Therefore, further research should evaluate water use through comparable functional units.

Among all international literatures reviewed, there were few studies that focused on Life-Cycle Water Assessment (LCWA) of residential buildings with limited emphasis on embodied water, including both initial and recurrent water usage. Embodied water was proved to surpass the water used in operation and end of life (EOL). This shows that the many studies focusing on the water use during operation only may fail to accurately identify the most optimum solutions for effectively improving the water efficiency of buildings, highlighting the significant impact of water efficiency during construction.

In addition, the residential case studies assessed for LCWA were of limited regions (mostly Australia), categories (mostly single-family detached houses), building materials (especially finishing materials), building components (doors, windows, sanitaryware ...etc.) and structural systems (mostly timber-framed). More residential buildings of wider regions, categories, materials and components should be assessed, developing a deeper conception of the life cycle water use in construction and reaching a more accurate resolution of direct and indirect requirements.

With very limited recent studies focusing on energy demand and Global Warming impacts, Egypt lacks LCA studies of water use in residential buildings despite having vast deserts and finite water resources for future housing expansion. Egypt also has no water inventory databases for building components and systems. The water inventory databases should be extended and adjusted to the properties of the related industries in Egypt. To achieve this task, the institutions must stimulate the manufacturers to use EPDs, providing standard information based entirely on the real lifecycle demands of products. This would then raise competition between manufacturers to introduce more efficient products, which would be most regarded by the local construction sector.

The study targets water-efficient construction of housing projects, which have direct impact on urban water planning of both existing and new cities. Studies should target water-efficiency of variously-classified residential buildings, especially the embodied water almost neglected in local green building regulations. This requires regulations for the efficiency of embodied water to be included in all green assessment tools and systems used for buildings in Egypt, promoting embodied water conservation for the Egyptian housing projects.

## References

Adalberth, K., Almgren, A. and Petersen, E. H. (2001) 'Life cycle assessment of four multi-family buildings', *Low Energy and Sustainable Buildings*, 2, pp. 1–21. Available at: <https://www.scopus.com/record/display.uri?eid=2-s2.0-33645665629&origin=inward&txGid=9C023782BC342A089EC2273B5ECB0F60.wsnAw8kcdt7IPYLO0V48gA%3A2>.

Ali, A. A. M. M. *et al.* (2015) 'Environmental Life Cycle Assessment of a Residential Building in Egypt: A Case Study', in *8th International Conference Interdisciplinarity in Engineering, INTER-ENG 2014*. Tirgu Mures, Romania: Procedia Technology, pp. 349–356. Available at: <http://www.sciencedirect.com/science/article/pii/S2212017315000511>.

Anderson, J. and Thornback, J. (2012) *A guide to understanding the embodied impacts of construction products*, Construction Products Association. London: Construction Products Association. Available at: [http://issuu.com/peinternational/docs/guide\\_understanding\\_the\\_embodied\\_impacts\\_of\\_constr%5Cnpapers2://publication/uuid/15139521-EE85-4A75-8928-26F1A11EC842](http://issuu.com/peinternational/docs/guide_understanding_the_embodied_impacts_of_constr%5Cnpapers2://publication/uuid/15139521-EE85-4A75-8928-26F1A11EC842).

Anon. (2011) *Water Security*. Available at: [http://maplecroft.com/about/news/water\\_security.html](http://maplecroft.com/about/news/water_security.html) (Accessed: 27 August 2015).

Arimah, B. C. *et al.* (2009) *Planning Sustainable cities - Global Report on Human Settlements*. Nairobi.

Basbagill, J. *et al.* (2013) 'Application of life-cycle assessment to early stage building design for reduced embodied environmental impacts', *Building and Environment*, 60, pp. 81–92. doi: 10.1016/j.buildenv.2012.11.009.

Blanchard, S. and Reppe, P. (1998) *Life Cycle Analysis of a Residential Home in Michigan, Physics*. University of Michigan. Available at:



<http://www.umich.edu/~nppcpub/research/lcahome/homelca.PDF>.

Blengini, G. A. and Di Carlo, T. (2010) 'The changing role of life cycle phases, subsystems and materials in the LCA of low energy buildings', *Energy and Buildings*, 42(6), pp. 869–880. Available at: <http://www.sciencedirect.com/science/article/pii/S03787778810000022>.

Bribián, I. Z.; Capilla, A. V., Usón, A. A. (2011) 'Life cycle assessment of building materials: Comparative analysis of energy and environmental impacts and evaluation of the eco-efficiency improvement potential', *Building and Environment*, 46(5), pp. 1133–1140. doi: 10.1016/j.buildenv.2010.12.002.

Cabeza, L. F. *et al.* (2014) 'Life cycle assessment (LCA) and life cycle energy analysis (LCEA) of buildings and the building sector: A review', *Renewable and Sustainable Energy Reviews*, 29(2014), pp. 394–416. doi: 10.1016/j.rser.2013.08.037.

CAPMAS (2016) *Statistical Yearbook*. Cairo: Central Agency for Public Mobilization and Statistics. Available at: [http://www.capmas.gov.eg/Pages/StaticPages.aspx?page\\_id=5034](http://www.capmas.gov.eg/Pages/StaticPages.aspx?page_id=5034).

Carre, A. (2011) *A Comparative Life Cycle Assessment of Alternative Constructions of a Typical Australian House Design*. Melbourne: Forest & Wood Products Australia Limited.

Chen, T. . . , Burnett, J. . and Chau, C. . . (2001) 'Analysis of embodied energy use in the residential building of Hong Kong', *Energy*, 26(4), pp. 323–340. Available at: <http://www.sciencedirect.com/science/article/pii/S0360544201000068>.

Clark, D. H. (2013) *What colour is your building?* London: RIBA.

Crawford, R. H. and Pullen, S. (2011) 'Life cycle water analysis of a residential building and its occupants', *Building Research and Information*, 39(6), pp. 589–602. doi: 10.1080/09613218.2011.584212.

Crawford, R. H. and Stephan, A. (2013) 'The Significance of Embodied Energy in Certified Passive Houses', *World Academy of Science, Engineering and Technology*, 7(6), pp. 475–481.

Cuéllar-Franca, R. M. and Azapagic, A. (2012) 'Environmental impacts of the UK residential sector: Life cycle assessment of houses', *Building and Environment*, 54, pp. 86–99. doi: 10.1016/j.buildenv.2012.02.005.

Dahou, K. *et al.* (2012) 'Climate challenges to Africa, a call for action', *OECD Journal: General Papers*, 2010(4), pp. 7–112. doi: 10.1787/1995283x.

Dixit, M. K., Culp, C. H. and Fernandez-Solis, J. L. (2013) 'System boundary for embodied energy in buildings: A conceptual model for definition', *Renewable and Sustainable Energy Reviews*, 21, pp. 153–164. doi: 10.1016/j.rser.2012.12.037.

Falkenmark, M. (1989) 'The massive water scarcity now threatening Africa -- why isn't it being addressed?', *Ambio*, 18(2), pp. 112–118. doi: 10.2307/4313541.

GBCA (2006) *The dollars and sense of green buildings: building the business case for green commercial buildings in Australia*. Melbourne. Available at: [https://www.gbca.org.au/docs/GBCA\\_dollars\\_sense08\\_sample.pdf](https://www.gbca.org.au/docs/GBCA_dollars_sense08_sample.pdf).

Gerilla, G. P., Teknomo, K. and Hokao, K. (2007) 'An environmental assessment of wood and steel reinforced concrete housing construction', *Building and Environment*, 42(7), pp. 2778–2784. Available at: <http://www.sciencedirect.com/science/article/pii/S0360132306002010>.

HBRC and EGBC (2011) *The Green Pyramid Rating System (GPRS) - First Edition For Public Review*. Cairo. Available at: [eg.saint-gobain-glass.com/download/file/fid/1246](http://eg.saint-gobain-glass.com/download/file/fid/1246).

Huovila, P. and Branch, U. N. E. P. S. C. and R. (2007) *Buildings and climate change: status, challenges, and opportunities*. Available at: <http://books.google.com/books?id=-lgab8igWgcC&pgis=1>.

Islam, H., Jollands, M. and Setunge, S. (2015) 'Life cycle assessment and life cycle cost implication of residential buildings - A review', *Renewable and Sustainable Energy Reviews*, 42, pp. 129–140. doi: 10.1016/j.rser.2014.10.006.

Kobayashi, Y. (2011) *Project Information Document (Appraisal Stage) - EG-Enhanced Water Resources Management - P118090*. Washington, D.C. Available at: <http://documents.worldbank.org/curated/en/2011/12/15554013/project-information-document-appraisal-stage-eg-enhanced-water-resources-management-p118090>.

McGrow-Hill Construction (2008) *Global Green Building Trends: Market Growth and Perspectives from Around the World, Issue 10 of SmartMarket Report: Design and Construction Intelligence*. USA. Available at: [www.greensource.construction.com/resources/smartMarket.asp](http://www.greensource.construction.com/resources/smartMarket.asp).

De Meester, B. et al. (2009) 'Exergetic life-cycle assessment (ELCA) for resource consumption evaluation in the built environment', *Building and Environment*, 44(1), pp. 11–17. Available at: <http://www.sciencedirect.com/science/article/pii/S0360132308000085>.

Mithraratne, N. and Vale, B. (2004) 'Life cycle analysis model for New Zealand houses', *Building and Environment*, 39(4), pp. 483–492. Available at: <http://www.sciencedirect.com/science/article/pii/S0360132303002191>.

Ortiz, O., Castells, F. and Sonnemann, G. (2010) 'Life cycle assessment of two dwellings: One in Spain, a developed country, and one in Colombia, a country under development', *Science of the Total Environment*. Elsevier B.V., 408(12), pp. 2435–2443. doi: 10.1016/j.scitotenv.2010.02.021.

Oyarzo, J. and Peuportier, B. (2014) 'Life cycle assessment model applied to housing in Chile', *Journal of Cleaner Production*, 69, pp. 109–116. doi: 10.1016/j.jclepro.2014.01.090.

Peuportier, B. L. P. (2001) 'Life cycle assessment applied to the comparative evaluation of single family houses in the French context', *Energy and Buildings*, 33(5), pp. 443–450. Available at: <http://www.sciencedirect.com/science/article/pii/S0378778800001018>.

Rossi, B. et al. (2012) 'Life-cycle assessment of residential buildings in three different European locations, basic tool', *Building and Environment*, 51, pp. 395–401. doi: 10.1016/j.buildenv.2011.11.017.

Stanley, J.-D. and Clemente, P. L. (2017) 'Increased Land Subsidence and Sea-Level Rise are Submerging Egypt's Nile Delta Coastal Margin', *GSA Today*, 27(5), pp. 4–11. doi: 10.1130/GSATG312A.1.

Stephan, A. and Crawford, R. H. (2014) 'A comprehensive life cycle water analysis framework for residential buildings', *Building Research & Information*, 42(6), pp. 685–695. doi: 10.1080/09613218.2014.921764.

Suh, S. et al. (2004) 'System Boundary Selection in Life-Cycle Inventories Using Hybrid Approaches', *Environmental Science and Technology*, 38(3), pp. 657–664. doi: 10.1021/es0263745.

Thormark, C. (2006) 'The effect of material choice on the total energy need and recycling potential of a building', *Building and Environment*, 41(8), pp. 1019–1026. doi: 10.1016/j.buildenv.2005.04.026.

UN DESA (2014) 'World Urbanization Prospects: The 2014 Revision'. United Nations - Department of Economic and Social Affairs. Available at: <http://esa.un.org/unpd/wup/CD-ROM/>.

Wallbaum, H. et al. (2012) 'Indicator based sustainability assessment tool for affordable housing construction technologies', *Ecological Indicators*. Elsevier Ltd, 18, pp. 353–364. doi: 10.1016/j.ecolind.2011.12.005.

# Low carbon, clay – based renders enhanced with polymers outperform current lime and clay renders in Hygric Properties.

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**Abstract:** The basic property of external renders in construction is considered to be the envelope waterproofing, while limited concern is paid to its high value or high values of relevant properties for all to ensure the envelope energy efficiency. Research conducted by BRE, NIHE or IEA estimated energy savings from wide scale retrofittings in UK. Energy efficiency was reduced by up to 50%, due to insulation failures in external walls, caused by rain penetration among other reasons. Mould and fungus were also present. An external render combining extremely low Water Absorption for rain penetration, high Vapor Permeability for breathability, and an ecological low carbon binder profile, is lacking in current UK market. In addition, besides the UK or European market, the Middle Eastern and African building stock are in need of a clay-based render with the aforementioned high value properties. Specifically, the significant Earthen structures of World Cultural Heritage currently preserved in the pre-referenced areas require frequent restoration, since the existing clay-based renders should be re-applied every rainy period or every 3-5 years maximum to avoid erosion and dismantling. Therefore, report explores a potential alternative to lime render, based on an innovative composite of nanoclay and waterproofing polymeric additives. 15 different clay-based specimens with 4 waterproofing polymeric agents and 2 breathable organic aggregates were tested for their physical (density, porosity) and hygric properties (Water absorption, Vapour permeability) using gravimetric and British Standards laboratory tests. 3 out of 15 specimens achieved the desired criteria of notably low absorption rates and high VP, outperforming those of known lime renders of UK market and relevant clay renders of existing academic research. The results indicate that they have a potential application as low carbon, highly waterproofing, breathable and compostable render solution, either in traditional porous buildings or in new structures.

**Keywords:** Clay-based render, nanoclay bio-polymeric composites, water absorption, vapour permeability

## Introduction

The basic property of external renders in construction is considered to be the envelope waterproofing, while limited concern is paid to its high value or those of relevant properties for all to ensure the envelope energy efficiency. Due to UK wide scale energy retrofitting in the last decade, organisations such as BRE (Stirling, 2001), NIHE (2014, p.18) or IEA (2007) have conducted research to estimate energy savings as a result of interventions. They concluded that buildings energy efficiency was reduced by up to 50%, due to insulation failures in external walls, caused by rain penetration. Mould and fungus were also present.

Current market renders exhibit similar limitations as traditional ones. Specifically, although cement renders display low Water Absorption (Wa), their low vapour permeability (VP) hinders moisture evaporation. Furthermore crystallization of soluble sulphate salts enhances cracking (Kopacz et al, 2013; Wilk et al, 2013). Although Lime renders display higher VP, they exhibit higher Wa than cement renders (Straube, no date), leading to cement mortar cracks (Izaguirre et al, 2009 ; Nezerka et al, 2014). New nanotechnology and

silicon-based renders provide high waterproofing, but low VP (Manoudis, 2009). In UK with high precipitation and porous structures an external render, which combines very low Wa properties to prevent rain penetration, with a high VP, to ensure breathability of the building and low embodied energy to reduce emissions, is lacking in current market and building practice.

On the other hand clay renders and structures have stood the test of time (NCCHS, 2014). Examples in UK is the “wattle and daub” construction system based on clay, sand, animal dung and straw applied on wooden lattice (Bowyer 1973, p.48-51 ; Graham 2003) or a plaster finish with clay, chopped straw, hay and dung added to daub (Davey 1961, p.40-41). Besides Europe, in Africa, the Middle East, Asia and Latin America there is a significant World Cultural Heritage of preserved Earthen Architecture where clay was the basic ancient structural material not only for housing, but also for wide scale villages, mosques, castles (Hall and Djerbib, 2004). Among villages, the 2,000 years old citadel of Arg-e-Bam in Iran is the largest city made by sun dried bricks in the world, or the 2,000 years old city of Shibam in Yemen is the tallest which comprises 5 to 11 storied sundried brick buildings still accommodating 7,000 residents in structures dating back to the 15<sup>th</sup> century (Revuelta et al, 2010). As for Mosques, Bob Dioulasso Grand Mosque in Burkina Faso and the Mosque of Djenné in Mali are entirely constructed with sun-dried mud bricks coated with clay render. Above are few out of various examples. Nevertheless, all referenced monuments require limited restoration after rainy periods or clay-based render reapplication every 3-5 years (Braun, 2017a), indicating the need for development of the existing clay renders to highly waterproofing ones. In fact, in 2006 the Technical University of Dresden was commissioned by the Iranian cultural authority ICHHTO and the UNESCO to perform tests for weatherproofing sundried brick structures for restoration purposes of the citadel Arg-e-Bam (Braun, 2017b). In addition, the material is highly valuable since over half of the world’s current population reside in earthen based homes especially in developing countries (Rodriguez and Saroza, 2006; Binici *et al.*, 2009).

In a final comparison between clay and lime and cement-based renders a Life Cycle Assessment displays that clay render exhibits a holistic ecological profile providing savings in Energy (2 times), CO<sub>2</sub> emissions (7 times) and in environmental contamination of the air, water and soil (2.5 times) compared to the other two (Melia et al, 2014)(Table 1)

Table 1. Earth, lime and cement renders ecological profile (Melia et al 2014).

<b>Renders</b>	<b>Cumulated Energy demand (MJ)</b> (Cradle to Gate Embodied Energy)	<b>Carbon Emissions (kg CO<sub>2</sub>eq)</b> (Cradle to Gate emissions)	<b>Environmental footprint (mPt)</b> (Environmental impact on 19 indicators in air, water, and soil)	<b>Ecological footprint (m<sup>2</sup> yr)</b> (land occupation for the material extraction, production, cultivation, etc)
earth renders	29.1	1.22	182	4.2
lime renders	63.2	7.64	501	19.4
cement renders	54.6	7.03	454	18.2

Acknowledging all the above, this research tested a potential alternative to external lime render, based on a clay binder of one synthesis, hoping to cover a gap in current market or in literature. The innovative ecological nanoclay composite was enhanced with four polymers (one synthetic and three organic) for waterproofing and two aggregates for breathability. The physical and hygric properties were compared to air-lime render and to a limited number of well known UK commercial lime products. The contribution of polymers and aggregates was also identified. The research may share important data, since published data is extremely limited on a) clay waterproofing agents (Minke 2006 ; Straube no date) b) renewable “green” organic polymers (bio-plastics) in construction industry, as opposed to petrol-based plastics c) nanoclay bio-composites in renders. However, bibliography for bio-



polymers is mostly associated with biodegradable films in food packaging industry, (Henriette de Azeredo, 2009) where casein polymer displays waterproofing (Cheema, 2015) and vapor permeable performance (Bonnaillie et al 2014) while cornstarch polymer displays low porosity (Srikaeo et al, 2005) plasticising properties but high water absorption. The research exploited the nanoscale (1nm) electric structure of clay as negative charged platelets in order to bond it with positive charged polymers, thus block water molecules (0,3-1mm) while allow vapor(1nm) to pass.

## Methodology

15 types of clay-based specimens (45 replicates) enhanced with 4 waterproofing polymers (based on siloxane, casein, cornstarch, bioplastic) and 2 breathable additives (perlite, straw) (Table 2) and one air-lime render (1:3) as control render (3 replicates), are tested for their Physical (Density, %Open Porosity) and Hygric properties (Wa, Vp, water penetration depth) are compared. The above tests are small part of a larger research programme, testing crucial properties in market industry (Giannatou, 2016). The research is linked with current literature. Specifically, the soil type used, its constituents, the ratios of its basic Category (Category A) and its control render(A0) (Table 2) align with those that G.Minke used in an educational workshop conducted in Greece (2008) in collaboration with Anelixi, an ecological research association. The research continues above work testing A0, while differentiates using different composition in the same waterproofing agents (casein mix, cornstarch mix) and adds 2 aggregates. All specimens have the same synthesis which is A0 composition. So new polymers and aggregates effect on Wa and Vp, which was the research target, is measured by comparing relevant specimens of different categories. As for constituents, sand mixture incorporated three distinctly different particle sizes. Hydrophobic, siloxane-based, synthetic polymer emulsion (400ml/m<sup>2</sup>) is applied in two layers, after the specimen dries. Organic polymer agents or bio-plastics (casein, cornstarch, bioplastic mixes) are produced under heat with the addition of positive ions (H, Na, Ca) in each solution with volume strictly not exceeding the 5%. Melt intercalation enhanced with manual shearing and compressing (Theng, 2012) is then used for the clay nano-composite production, intercalating positive charged polymers into clay negative sheets.

Table 2. Constituents and Ratios of specimens tested.

Specimen synthesis	Code				
Clay renders _A Category		Clay renders _B Category		Clay renders _Γ Category	
Basic(B) : 0 aggregate		Basic(B) : 1 perlite		Basic(B) : 1 straw	
Basic (B)	<b>A0</b>	B/perlite	<b>B0</b>	B/straw	<b>Γ0</b>
B/ siloxane coating	<b>A1</b>	B/perlite/ siloxane coating	<b>B1</b>	B/straw/ siloxane coating	<b>Γ1</b>
B/ corn starch mix	<b>A2</b>	B/perlite/ corn starch mix	<b>B2</b>	B/straw/ corn starch mix	<b>Γ2</b>
B/bioplastic mix	<b>A3</b>	B/perlite/bioplastic mix	<b>B3</b>	B/straw/bioplastic mix	<b>Γ3</b>
B/casein mix	<b>A4</b>	B/perlite/casein mix	<b>B4</b>	B/straw/casein mix	<b>Γ4</b>
<b>Air-lime Render Control</b>	<b>L</b>	<b>1 lime : 3 sand</b>			

The %Open Porosity (OP) (%ratio between the difference of saturated and dry mass of the specimen to its dry volume) examines all additives effect on the porous structure and the OP relation to Wa examines the value connection to waterproofing. Water absorption was tested in accordance with British Standard BS EN ISO 15148 (2002) guidelines. The test measures the rate of water absorption of a specimen by capillary action during 24hrs, and defines the water absorption coefficient ( $A_w = \text{kg/m}^2 \text{ sec}^{-1/2}$ ). Specimens were sealed on sides (aluminium foil, 100% virgin beeswax) and stored at 28°C and 50%RH in the climate chamber to stabilize their total mass to 0.1%. They were submerged by 5mm in water cups and stored in a climate chamber(28°C, 50%RH) for 24hrs. Seventeen weightings during the



24hrs were recorded, instead of the 8 required by British Standards, to minimize error from 4% to 1.5% and form the Wa diagram in high precision.

VP testing (dry cup) measures the resistance ( $\mu$ -value) in the vapor flow through a specimen in a steady state in accordance with BS EN ISO 12572(2001) and accuracy methods required. Specimens whose sides were primarily sealed with foil tape and wax, were sealed on a cup of similar diameter incorporating desiccant ( $\text{CaCl}_2$ , size<3mm) and a USB data logger ( $^{\circ}\text{C}$ , %RH) to measure the VP of stagnant air. All specimens were located in a climatic chamber (TAS, ECO 900) ( $23\pm5^{\circ}\text{C}$ ,  $50\pm5\%\text{RH}$ ) for 6 days. An electronic scale ( $\pm0.005\text{gr}$ ) was used for specimens periodic weighting. The  $\mu$ -value was measured as the ratio between the VP of stagnant air (inside a cup) and the VP of the specimen under  $23\pm5^{\circ}\text{C}$  and  $50\pm5\%\text{RH}$ .

## Results and Discussion

### Drying properties

#### Drying Days and Shrinkage

Polymers increased Drying time for 9 out of 12 specimens, working as coagulation retarders, except for 3 (A4, B4,  $\Gamma$ 4) all casein-based ones (Figure 1). Specifically, only casein polymer decreased Drying days in all categories (coagulation accelerator), in fact by 2 days, with the lowest drying period lasting for 6,5 days, displayed by the straw-casein specimen ( $\Gamma$ 4). A potential cause may be the limited water ratio (10%) used in casein mix production compared to cornstarch (60%) and bioplastic mix (40%). According to literature, the investigated specimens displayed a promising Drying performance, since the A0 dried (10 days) faster than G. Minke (2006, p.28) sandy clay-based mortar (14 days,  $20^{\circ}\text{C}$ , 44%RH). Regarding Aggregates, they performed differently. Perlite increased Drying time (coagulation retarder) for 4 (B0, B1, B3, B4) out of 5 specimens of Category B compared to Category A, while straw significantly decreased Drying time (coagulation accelerator) for all 5 specimens of Category  $\Gamma$  ( $\Gamma$ 0,  $\Gamma$ 1,  $\Gamma$ 2,  $\Gamma$ 3,  $\Gamma$ 4) compared to Category A (Figure 1). The straw-casein specimen ( $\Gamma$ 4) displayed the lowest Drying period (6,5 days). Similarly in literature, increased hemp ratios decreased Drying time in clay-dung plasters (Mareike, 2013). Overall, when compared to lime render 4 out of 15 researched specimens ( $\Gamma$ 0,  $\Gamma$ 1, A4,  $\Gamma$ 4) displayed lower Drying period, with lowest value (6,5 days) exhibited by the straw-casein specimen ( $\Gamma$ 4).

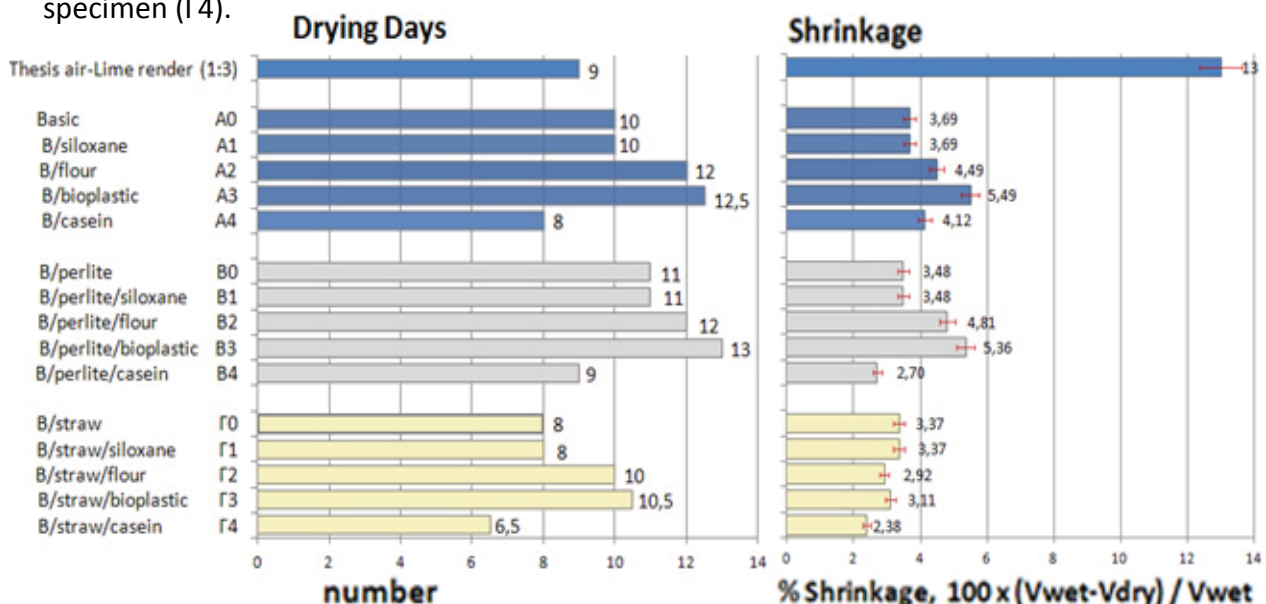


Figure 1. Drying Days (number) and Shrinkage (%) values of specimens tested (Mean value,  $\pm 95\text{CI}$ ).

The above could potentially be a significant advantage in practical and market terms in comparison to lime renders for the following reasons. In UK in winter (October-March) lime render drying time ranges from 15 days (Frew, 2007) to almost 90 days, if lime carbonation is considered part of the drying process for its solidification (Nežerka et al, 2014). Furthermore, during frost days (< 8°C) lime render carbonization stops, and the material is subjective to cracks, endangering cohesion (Holmes & Wingate, 2002, p. 63) (Norval, 2012, p.61). In addition, in summer temperatures over 28°C, quick drying is enhanced risking carbonization process (IHBC, 1998). On the contrary, Thesis renders solidification relies on evaporation only, regardless of weather conditions. A test of binding tension N/mm<sup>2</sup> (Minke, 2006, p.33) along with Freeze-thaw test should be further conducted for Thesis specimens. If results are positive, clay render may be an alternative to lime render in areas, during seasons and under timescales that lime cannot deliver.

Polymers increased Shrinkage in 5 (A2, B2, A3, B3, A4) out of 9 specimens. Four of them were waterproofed with cornstarch and bioplastic polymers (-11% to -54%), which proved that those polymers were shrinkage enhancers (Figure 1). Potential cause maybe their high mix of % water percentage and their hydrophilicity, which caused high shrinkage after evaporation. Siloxane did not change the shrinkage percentage in any of its three specimens. However, casein was the only polymer to reduce Shrinkage in two of three categories (B4, F4) (22-29%), working as a shrinkage controller. Its combination with perlite (B4) and straw (F4) displayed the lowest shrinkage 2,7% and 2,38% respectively. Generally, Thesis specimens exhibited medium to high % shrinkage (2.38-5.36%) while no mesh or animal hair was used to reduce values. In Ashour et al, (2010) the %shrinkage of clay-based specimens without fibres in different curing temperatures ranged from 2-3% in 30°C to 70°C.

Both Aggregates (perlite and straw) performed as shrinkage controllers decreasing the shrinkage of 9 out of 10 specimens to a limited or medium degree (5.75%-42%). Their contribution was also obvious to the basic A0, whose shrinkage was reduced by 5,75% (B0) and 8.63%(F0) after perlite and straw addition (Figure 1). Literature researchers found higher shrinkage reductions. Ashour et al (2010) measured a 50% shrinkage reduction, as straw additives reduced the research clay-based renders shrinkage from 2-3% to 1-1.5%. Minke (2006, p. 40) research showed an average 60% reduction, since its sandy loam mortar without aggregate had 1.3% shrinkage and with coir, flax straw, rye straw was reduced to 0.6%, 0.6%, and 0.4% respectively. Thesis renders due to limited water ratio, and high compressing potentially created a very compact material with limited shrinkage potential compared to academic research.

Finally, all specimens (14/14) displayed 57.70% to 81.60% lower shrinkage than lime render. Even A0 displayed 71.55% less Shrinkage than lime render, implying that its primary composition displays anti-shrinkage properties by itself. Shrinkage values of Nežerka (2014) and Izaguirre (2009) agree with the values for air lime specimen in this research (13%) since their air-slaked lime renders displayed circa 10-13% shrinkage during the first 90 days. Bardos et al (2000) for different traditional lime renders measured an average of 10% shrinkage for 28 days.

### ***Physical properties***

#### ***Density and Porosity***

In 10 of 12 specimens the addition of polymers decreased their Density, except in the basics A1, F1 (Figure 2). This suggests that they work as both light fillers and binders. In addition, casein polymer was found lighter as a filler compared to aggregates, such as perlite or straw. Specifically, comparing A0 density, to B0 and F0 which were aggregate-based, they reduced the A0 density less than the casein-based A4. Both aggregates did decrease Density of 11

out of 12 specimens, except the A1, performing as light fillers, aligning with relevant literature data (Straube, no date; Ashour et al, 2010 ; Minke, 2006, p. 49). All specimens displayed lower density from 4% to 26% compared to the research control lime render (1780kg/m<sup>3</sup>). Significant cause for lower density of the clay-based renders is that both polymers and aggregates (30–150 kg/m<sup>3</sup>) work as lighter fillers than sand (1300-2000 kg/m<sup>3</sup>).

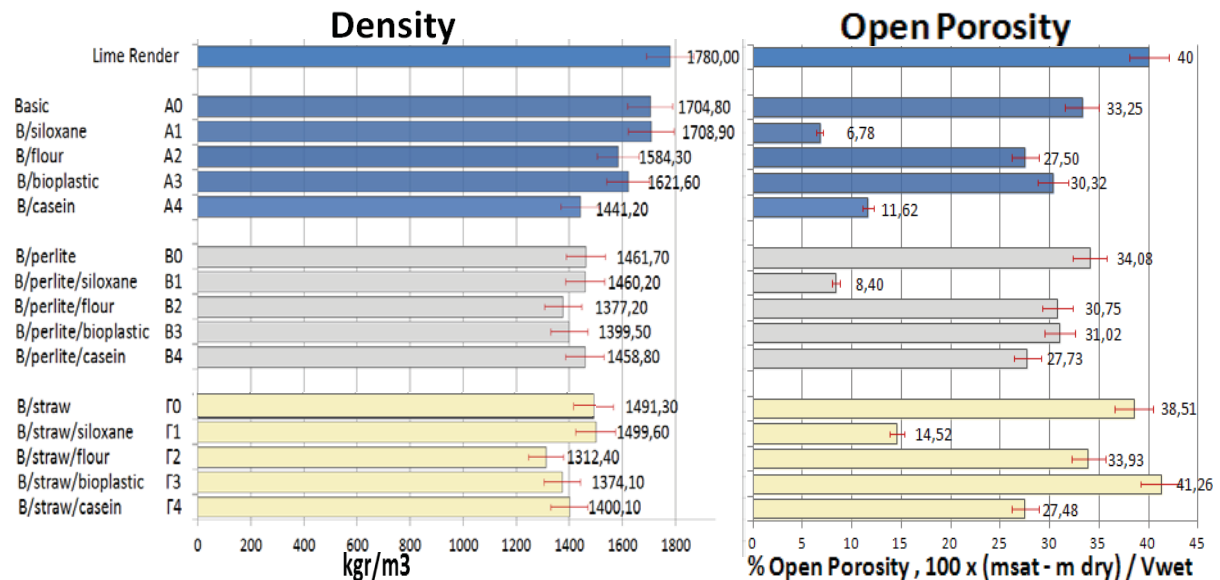


Figure 2. Density (kg/m<sup>3</sup>) and Open Porosity (%) values of specimens tested (Mean value, ±95CI).

Polymers decreased the % Open Porosity of 11 out of 12 specimens except Γ3(Figure2). The highest %OP decrease was achieved by siloxane coating (A1, B1, Γ1)(62%-79%) and by the organic casein (A4,B4,Γ4) (28%-65%).This implies that polymers nano-structure turn them into high porosity reducers but not pore blockers (%OP>7%). Aggregates (perlite and straw) increased the porosity of all 10 polymer-based specimens, with straw exhibiting the higher increase in all categories (Γ1, Γ2 ,Γ3, Γ4) (15%-136%) and perlite (B1,B2,B3,B4) the lower (2%-138%). All of the above indicate that aggregates work detrimentally for the external renders porosity and potentially for their Wa. This is against existing orthodoxy, practice and market trend, where straw and hemp is frequently used in external renders. 13 out of 14 specimens displayed 45% to 255% lower porosity than lime, except Γ3. Siloxane and casein when mixed with Category A specimens, A1 and A4 skyrocketed their porosity reduction to 255.54% and 218.08% respectively (Figure1). Minke (2006) and Straube(no date) also tested siloxane to be a high porosity reducer on clay and cement respectively.

## Hygric properties

### Water Absorption

Polymers significantly decreased Wa for 10 out of 12 specimens by 23-96% compared to their non-glued Category Basic (Figure 3) displaying a significant waterproofing ability. Best sealers proved all siloxane mixes (A1, B1, Γ1)(90%-96%) and all casein mixes (A4,B4,Γ4)(76%-92%). Aggregates significantly increased Wa for 7 from 10 specimens by 26-178% compared to the relevant specimen of Category A incorporating the same polymer. This implies that perlite and straw combined with polymers work as water absorbers but alone in clay specimens (B0,Γ0) work as water reducers (5,25% -11,70%) complying with current practice. In literature, aggregates usually work as absorbers (Ashour, 2010; Minke, 2006). Thirteen to 14 specimens displayed lower Wa than A0 and 14 to 14 than lime render. Earth-based

specimens proved to be better sealers by 36%-97% compared to air lime render control. In fact the siloxane-based A1(0,00203 kg/m<sup>2</sup> sec<sup>1/2</sup>), and the casein-based A4 (0.00689 kg/m<sup>2</sup> sec<sup>1/2</sup>) exceeded most commercial renders performance (Table 3). Furthermore A1 met and A4 exceeded the performance of relevant specimens of Gernot Minke (2006) which displayed Wa 0.0 017 kg/m<sup>2</sup> sec<sup>1/2</sup> and 0.0117kg/m<sup>2</sup> sec<sup>1/2</sup> respectively (Table 3).This aligns with current literature and goes against existing orthodoxy and market practice that associates clay renders with inner use only.

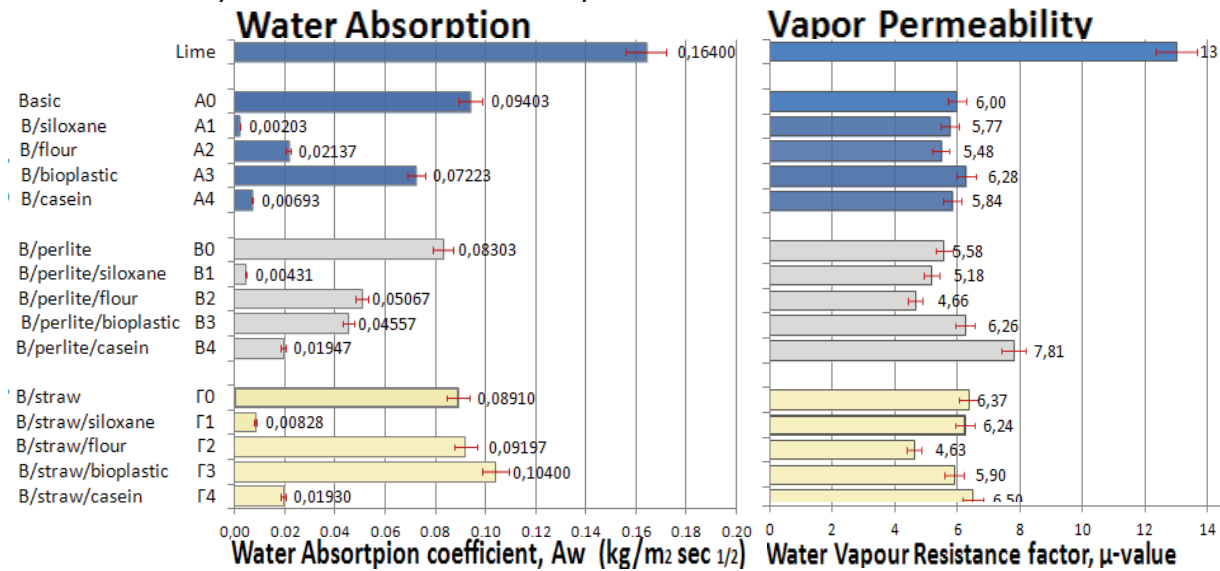


Figure 3. Water Absorption coefficient values,  $A_w$  (kg/m<sup>2</sup>sec<sup>1/2</sup>) of specimens tested (Mean value,  $\pm$ 95CI).

Figure 4. Vapor Resistance factor values,  $\mu$  (unitless) of specimens tested (Mean value,  $\pm$ 95CI).

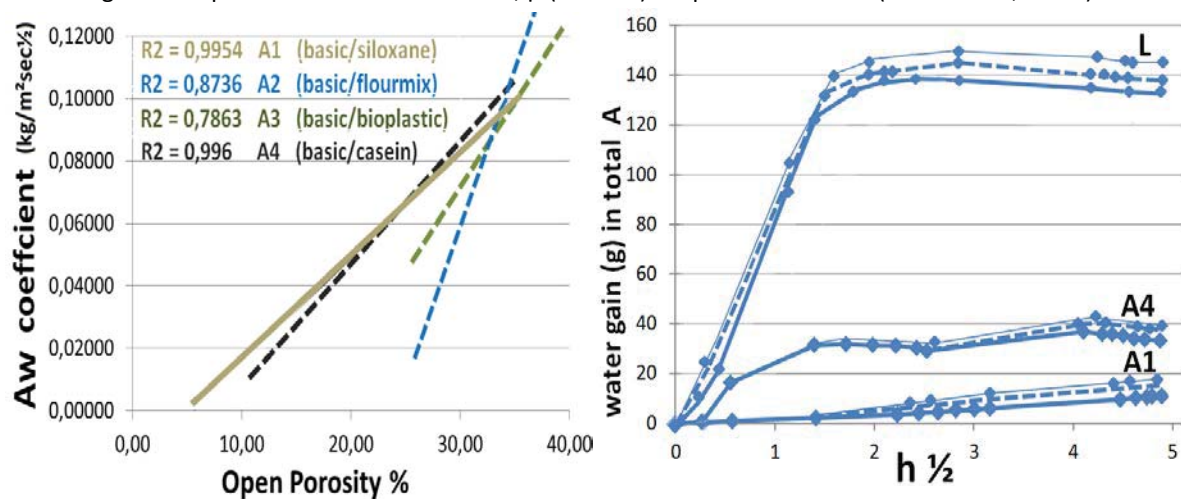


Figure 5. Relation of Water Absorption coefficient,  $A_w$  (kg/m<sup>2</sup>sec<sup>1/2</sup>) to %Open Porosity (Category A).

Figure 6. Water Absorption gain (g) per time, during the 24hrs Wa test.

Polymers inclusion did result in a strong positive Porosity/Wa correlation for 9 out of total 12 specimens, except for B2,  $\Gamma$ 2,  $\Gamma$ 3 (Giannatou, 2016)(Figure 5). This implied that polymers not only reduced the number and water size pores of the specimens, but this maybe among the reasons that turned them into waterproofing agents. Siloxane (A1,B1, $\Gamma$ 1) ( $R^2$ =0.95-0.99) and casein (A4,B4, $\Gamma$ 4)(  $R^2$ =0.92-0.99) had the strongest correlations in all 3 categories(Figure 5), experiencing the highest porosity reduction which implied that their polymers final porous system was the finest of all, closing specimens pores in a higher level. Category A specimens (A1, A2, A3, A4) displayed the strongest correlations of all categories



( $R=0.78-0.99$ ) (Figure 5), and a higher waterproofing capacity implying that all polymers are more waterproofing, when specimens acquire no aggregates.

Specimens Wa performance was further examined by; a) measuring the water penetration depth of specimens after the Wa test by cross-sectioning b) assessing the Wa diagrams. In water penetration depth test air-Lime render was completely saturated (25mm) after 24hrs, while A1,B1 displayed no water penetration after 24hrs or 42hrs, and A4 which displayed 5,7mm(24hrs) and 10mm(42hrs) respectively (Figure 7). The siloxane based specimens (A1,B1) were light in color and weight, showing little signs of moisture. The casein based A4 displayed water ingress that has been blocked up to a distinct horizontal level (Figure 7). The Wa diagrams is concurrent with the above (Figure 6). Samples A1 and B1 displayed a very low but steady Wa rate since its siloxane hydrophobic coating repelled water, while the casein polymer performance in A4 seemed to have blocked water intrusion twice. The above relates to the known “clay tortuous path” mechanism (Figure 8) (Henriette de Azeredo, 2009) where successful intercalation (insertion) of polymer into the clay stratification of horizontally bonded layers blocks water intrusion.

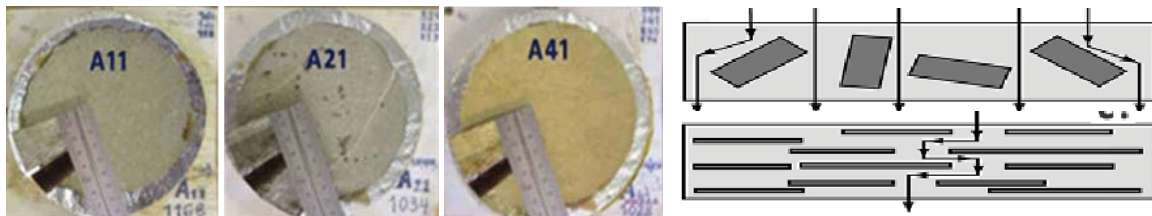


Figure 7. Depth of water penetration (mm) in the relevant test for A11,A21,A41.

Figure 8. Clay platelets versus polymer-clay platelets dispersion after compressing(Tortuous path).

### Vapour Permeability

Paradoxically polymers did increase, instead of decrease the Vapor Permeability of 9 out of 12, when compared to their Basic specimen (2%-27%) working as vapor enhancers (Figure 4). In addition, some polymers and especially cornstarch mix when added to A0 increased VP more than even perlite (B0) or straw (Γ0). This implies that some glues could replace equally or even better perlite and especially straw to increase specimens VP property. Potential cause could be that most polymers reduce the pores sizes, and since they are hydrophilic they enhance attached vapor molecules velocity (0.2nm) according to Bernoulli law (Portella, 2009). From the 2 aggregates tested, perlite ( $\mu$ -value=2) did increase the VP of all specimens (0.3%-15%) except the B4, but paradoxically straw decreased the VP of all (-11% - -6%), except Γ2 and Γ3. This is logical and revealed that the clay-based specimen is highly Vapour Permeable by itself ( $\mu$ - value<6) and straw is simply less ( $\mu$ - value>6). No academic data has found straw ( $\mu$ -value>6) to reduce specimens VP, given that most specimens in literature displayed ( $\mu$ -value>6) (Minke, 2006; Ashour, 2010; Straube, no date). Also this is against existing orthodoxy and practice, since straw is always considered a VP enhancer for plaster and renders, which maybe not always be the case, in low  $\mu$ -value specimens.

Eight out of 14 specimens outperformed A0, and 15 out of 15 outperformed air-lime render, displaying higher VP between 39% to 64 % (Figure 4).Thus, they are considered highly VP agents. It was the polymers that primarily enhanced specimens VP, but furthermore the clay-based specimens synthesis was further reason, since A0 (the basic specimen of all categories) was 53.80% more vapor permeable than air-lime render control. In comparison to academic data, a notable finding is that the 3 best specimens tested by Gernot Minke(2006), the casein-based, the flour based and the siloxane based specimens



(Table 3) displayed lower VP ( $\mu=13$ ) than the research relevant specimens ( $\mu=5.18-6.27$ ). Furthermore, the research specimens displayed superior performance to well-known and widely used market lime renders as displayed below (Table 3).

## Conclusions

Polymers decreased Density (10/12) for 10 out of 12 specimens, %Open Porosity (11/12) for 11 out of 12, Wa (10/12) for 10 out of 12 while increased VP (9/12) for 9 out of 12 (Table 3). This implies that they worked beneficially as light fillers and binders, porosity reducers, strong waterproofers and VP enhancers at the same time. Furthermore, some proved better VP enhancers, than perlite and straw, meaning that they could replace them. The polymers contribution to porosity reduction, waterproofing and breathability increase implies that they decrease pore size, so as to block free water (0.3-1mm) but allow vapor (1nm) entrance. The synthetic polymer of siloxane and the degradable bio-polymer (bio-plastic) as casein mix displayed the best performance. However, the majority of polymers increased Drying period (9/12) and % Shrinkage (5/9) of specimens, performing detrimentally as coagulation retarders and shrinkage enhancers, with the exception of casein. Casein, when combined with straw ( $\Gamma 4$ ) decreased both values, displaying the lowest Drying period of all (6,5 days) and the lowest Shrinkage (2,38%). Casein limited water percentage may be the reason for performance on both values.

Table 3. Water Absorption ( $\text{kg/m}^2 \text{ sec}^{1/2}$ ) and Vapor Permeability performance ( $\mu$ ) of research renders compared to literature and market products.

EXTERNAL RENDER	Density	WA	$\mu$
LITERATURE LIME RENDERS (TRADITIONAL 1:3)	( $\text{kg/m}^3$ )	( $\text{kg/m}^2 \text{ sec}^{1/2}$ )	(unitless)
AIR-LIME (1:3) MINKE (2006)	1750 (dry)	0,154	11,00
AIR-LIME (1:3) STRAUBE (no date)	1748 (dry)	0,153	9,85
AIR-LIME (1:3) THESIS(2016)	1780 (dry)	0,190	13,00
LITERATURE CLAY RENDERS (RESEARCH RELEVANT)			clayey-silty
EARTH RENDER/SILOXANE (BS 15 Wacker) MINKE (2006)	x	0,0017	12-14
EARTH RENDER/2 COATS (8 CASEIN:1 LIME) MINKE (2006)	x	0,0117	12-14
EARTH RENDER (2% RYE FLOUR MX) MINKE (2006)	x	0,019	12-14
EARTH RENDER STRAUBE (no date)	1759 (dry)	0,068	7,03
EARTH RENDER MIX (5 LIMEWASH COATS) STRAUBE (no date)	1408 (dry)	0,047	7,18
CLAY RENDER MIX (50% LIME BY VOLUME) STRAUBE (no date)	1741 (dry)	0,092	7,26
MARKET LIME RENDERS			
MAPEI	1750 (bulk)	$\leq 0,025$	20,00
UNILIT	1800 (bulk)	$\leq 0,006$	10,00
KEIM	x	$\leq 0,025$	10,00
BAUMIT	x	$\leq 0,025$	10,00
LIMETEC	1600	$> 0,12$	$< 8$
REMMERS	1100	0,129	$< 15$
THESIS CLAY RENDERS			
A1 (SILOXANE-CLAY RENDER)	1708 (dry)	0,00203	5,77
B1 (SILOXANE-CLAY RENDER)	1440 (dry)	0,00403	5,18
A4 (CASEIN-CLAY RENDER)	1441 (dry)	0,00698	5,84
$\Gamma 1$ (SILOXANE-CLAY RENDER)	1499 (dry)	0,00803	6,24
A2 (FLOUR-CLAY RENDER)	1584 (dry)	0,021	5,48

As for aggregates, although they decreased density (11/12) they increased porosity (10/10) and Wa (7/10). As for VP, perlite increased it (4/5) while straw decreased it (3/5). Since they proved to be porosity enhancers, water absorbers with mixed performance in VP, their performance proved detrimental in the end. On the other hand, regarding %Shrinkage both aggregates proved to be shrinkage controllers (9/10). As for their Drying period, perlite performed detrimentally as a coagulation retarder (4/5) while straw performed beneficially as an accelerator (5/5). As for clay-based specimens, they proved to be lighter (15/15), less porous (13/14), more waterproofing(14/14) and more vapour Permeable(15/15) than air-lime render (1:3) control.

A notable research finding is that research specimens (A1, B1, A4) outperformed both in  $W_a$  and  $V_p$  a) similar specimens in literature and, b) current commercial lime renders in UK Market (Table3). Regarding the first, A1 siloxane-based specimen displayed almost equal  $W_a$  ( $0.002 \text{ kg/m}^2 \text{ sec}^{1/2}$ ) to G. Minke (2006) relevant specimen ( $0.0017 \text{ kg/m}^2 \text{ sec}^{1/2}$ ) and the A4 casein-based specimen ( $0.0069 \text{ kg/m}^2 \text{ sec}^{1/2}$ ) displayed half  $W_a$  ( $0.0117 \text{ kg/m}^2 \text{ sec}^{1/2}$ ). Furthermore, both investigated specimens were twice as vapour Permeable ( $\mu=5.77$ ) thus breathable, as the above referenced specimens of academic literature ( $\mu=12-14$ ). Regarding the second, further research in specimens performance in adhesion, durability, thermal conductivity, reaction to fire following the BS EN 15824:2009 guidelines for renders based on organic binder, will be conducted to prove the product market applicability. Also their exposure in real weather conditions could further verify the above.

Assessing  $W_a$  and  $V_p$  results, clay-based specimens with polymers show potential as alternatives to external lime render when examined in Drying and Hygric properties. They display a comparative advantage to lime renders, since they combine higher waterproofing against rain, with higher breathability against mold, while maintaining a lower energy, carbon and waste profile at the same time, on lower production cost. This may enable potential application both in contemporary uses as well as in highly problematic ones, where other materials may not deliver. Specifically, in cold rainy European climate, research renders show potential to support energy efficiency, in the following areas: a) historic stone structures, b) existing traditional brick structures c) new structures to maintain high energy efficiency, while keeping a multilevel environmental profile in a life cycle assessment d) flood- prone areas e) areas of heavy rain conditions f) underground limited ventilation areas g) inner high humidity areas of bathrooms, swimming pools, or saunas. In addition, in hot climates there is wide scale building stock of historic Earth-based structures of Cultural Heritage (Africa, Middle-East, South America, West Asia) where clay based renders with high waterproofing performance could provide a more compatible solution for restoration services compared to existing renders. Those renders could cover the gap in market industry already mentioned in the introduction.

Additionally, from a general perspective, switching an economy from a lime to a clay-based material production holds significant macro and micro-economic benefits, in a national level especially for developing countries, as well as in an industrial level too. In a potential production of a material similar to research render, firstly national importation costs of readymade lime products or excavation industrial costs of raw lime material are eliminated depending on the country resources availability. Regarding the processing, no kilns of  $1400^\circ\text{C}$  are used for calcination, since material production requires heat no higher than  $80^\circ\text{C}$ , eliminating industrial equipment, heavy industrial electricity costs and industry high share in the national electricity grid. In that case, electricity reserves can be used for the benefit of the citizens and further national development, eliminating national electricity importation or blackouts. Regarding pollution of the air, water and soil, research render carbon emissions amount nearly to 1/7 compared to those of a lime render according to literature (Melia et al, 2016) while all substances except for siloxane are purely organic, polluting neither the water nor the soil, eliminating any national waste treatment costs. All environmental values of a typical clay and lime render assessed in Melia et al (2016) research are thoroughly referenced in the introduction. As for disposal, the research render shows potential to promote its recycling instead of its landfill disposal reducing national costs, since it can be 100% biodegradable when it is siloxane –based or it can be even 100% compostable when it is casein-based.

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## References

- Ashour, T., et al (2010) Absorption and desorption behavior of some clay–sandy plasters reinforced with natural fibers, *Journal of Building Appraisal*, 6 (7), pp. 171-181
- Bowyer, J. (1973) *History of Building*. London: Crosby Lockwood Staples. pp. 48-51
- Bonnaillie, L., et al (2014) Casein Films: The Effects of Formulation, Environmental Conditions and the Addition of Citric Pectin on the Structure and Mechanical Properties, *Polymers*, 6, pp. 2018-2036
- Binici, H., O. Aksogan, D. Bakkak, H. Kaplan and B. Isik, (2009) Sound insulation of fibre reinforced mud brick walls, *Construction and Building Materials*, 23, pp. 1035-1041.
- Braun, J. (2017a) Investigations into the improvement of the weather protection of unburnt brick masonry, part 1 *Mauewerk European Journal of Masonry*, 21(2) pp. 114 - 128
- Braun, J. (2017b) Investigations into the improvement of the weather protection of unburnt brick masonry, part 2 *Mauewerk European Journal of Masonry*, 21(3) pp. 188 – 203
- Cheema, M., et al (2015) The association of low-molecular-weight hydrophobic compounds with native casein micelles. *Journal of Dairy Science*, 98(8), pp. 5155-5163
- Davey, N. (1961) *A History of Building Materials*. London: Phoenix House.
- Giannatou, A. (2016) Do clay-based renders with waterproofing and vapor permeable additives show potential to be an alternative to lime renders in UK, when examined on Water Absorption and Vapor Permeability? Ms Arch. Centre for Alternative Technology, University of East London
- Graham, T., (2003) Wattle & Daub: Wiltshire Case Study, published PHD Thesis, University of Bath
- Hall, M. and Y. Djerbib, (2004) Rammed earth sample production: Context, recommendations and consistency, *Construction and Building Materials*, 18, pp. 281-286.
- Henriette de Azeredo (2009) Nanocomposites for food packaging applications, *Food Research International*, 42, pp.1240–1253
- International Energy Agency (IEA)(2007) Tracking Industrial Energy Efficiency and CO2 Emissions
- Izaguirre, A., et al (2009) Effect of water-repellent admixtures on the behaviour of aerial lime-based mortars, *Cement and Concrete Research*, 39(11), pp. 1095–1104
- Kopacz, A., et al (2013) The effect of composition of Roman cement repair mortars on their Salt Crystallization resistance and Adhesion , *Procedia Engineering*, 57, pp.565-571
- Manoudis , P., et al (2009) Fabrication of super-hydrophobic surfaces for enhanced stone protection, *Surface and Coatings Technology*, 203(10–11), pp. 1322–1328
- Melia, P., (2014) Environmental impacts of natural and conventional building materials: a case study on earth plasters, *Journal of Cleaner Production*, 80, pp. 179–186
- Minke, G.,(2006) Building with earth. Design and Technology of a Sustainable Architecture. Birkhauser.
- National Conservation Centre of Historic Scotland (NCHS) (2014) Lime Mortars in Traditional Buildings
- Northern Ireland Housing Executive (2014) Cavity wall insulation Inspection Report
- Nezerka, V., et al (2014) Comprehensive study on mechanical properties of lime-based pastes with additions of metakaolin and brick dust, *Cement and Concrete Research*, 64, pp.17–29
- Portella, G., (2009) Determinants of Water Permeability through Nanoscopic Hydrophilic Channels, *Biophysical Journal*, 96(3), pp.925–938
- Rasper, V., et al (1979) Measurement of Hydration capacity of wheat flour starch mixtures, *Cereals Chemistry*, 57(1), pp.27-31
- Revuelta- Acosta, J.D. et al (2010) Adobe as a Sustainable Material: A Thermal Performance, *Journal of Applied Sciences*, 10, pp.2211-2216.
- Rodriguez, M.A. and B. Saroza, (2006) Determination of the optimum composition of adobe brick for a school in Cuba, *Materiales de Construcción*, 56(282), pp. 53-62.
- Srikaeo, K., et al (2006) Microstructural changes of starch in cooked wheat grains as affected by cooking temperatures and times, *Food Science and Technology*, 39, pp.528–533
- Stirling, C., (2001) Insulating masonry cavity walls: Part 2 - Principal risks and guidance. London: BRE Electronic Publications
- Straube (no date) Moisture Properties of Plaster and Stucco for Strawbale Buildings
- Theng, B.(2012) Formation and Properties of Clay-Polymer Complexes.Oxford: Elsevier
- Wilk, D., et al (2013) Shrinkage cracking in Roman cement pastes and mortars, *Cement and Concrete Research*, 53, pp.168–175

# Thermal bridging through timber elements of strawbale construction: exploring its extent, with particular reference to self-build projects

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**Abstract:** Strawbale building offers possibilities for low-carbon construction, with low emissions in production and operation. Its use is increasing, in particular for self-build projects. To ensure energy efficiency the availability of repeatable construction details with known thermal performance is important. Many such details in strawbale walls contain timber elements, which represent thermal bridges, reducing building fabric energy efficiency. The extent of two-dimensional thermal bridging through a range of standard strawbale construction details provided by Straw Works is calculated. Results are compared to requirements for UK Building Regulations and the Passivhaus standard. The standard details are found to perform significantly better than required for UK Building Regulations (improvements of 54% to 97% noted) indicating that existing energy assessments of strawbale buildings may overestimate energy use. Thermal performance of windows and door details falls short of Passivhaus requirements, suggesting that these would benefit from reduced thermal bridging. Simple adaptations are analysed, seeking improved thermal performance without sacrificing ease of construction. These are found to reduce thermal bridging by up to 44% over the standard details, but still fall short of Passivhaus requirements. Thermographic surveys are conducted of the standard details in a selfbuild strawbale house, broadly confirming heat flow indications from software analysis. Further work is indicated, to analyse a wider range of construction details and adaptations, and to explore a more radical redesign of the details.

**Keywords:** thermal bridging, strawbale building, energy efficiency, low-carbon construction, timber

## Introduction

Buildings account for 40% energy use (EU, 2010), through production of the raw materials used to build them, in construction, in use (primarily through heating and cooling), and in demolition (Dixit *et al.*, 2012). Reducing the carbon and energy load of a building most effectively means using materials with low embodied carbon that result in a thermally efficient building envelope.

Strawbale offers one means of achieving this, being a waste product with an embodied energy of 0.01 kgCO<sub>2</sub>/kg (Hammond and Jones, 2011), and good insulating properties. There are various means of constructing with straw, but all involve timber elements (e.g. to provide fixing points for windows, or beams to attach and spread the load of roof structures). These timber elements form thermal bridges.

Thermal bridges are weaknesses in the insulating building envelope, with higher heat flows than surrounding areas (Ibrahim *et al.*, 2014) and accompanying increased condensation risk (Ascione *et al.*, 2012). Estimates vary for the level of additional heat flow caused by thermal bridges; design and level of insulation will affect their impact (Martin *et al.*, 2012). Mao and Johannesson (1997) quote an additional heat flow of between 5 and 39% through structural thermal bridges. Theodosiou and Papadopoulos (2008) found thermal bridges increased annual heating load by between 15 and 23%. Evola *et al.* (2011) found that work to reduce thermal bridging could reduce primary energy demand by 25% in terraced houses and 17.5% in semi-detached houses.

The regulatory framework for the reduction of energy consumption stems from the EU Energy Performance of Buildings Directive. In the UK this is enacted through Part L of the

UK Building Regulations (UKBR). This requires that new buildings be constructed with “no reasonably avoidable thermal bridges” (NBS, 2014), and sets out the standards by which this is judged. There are maximum  $\Psi$  values (default values), and approved  $\Psi$  values where Accredited Construction Details (ACDs) with improved and calculated thermal performance are used. Alternatively,  $\Psi$  of construction details can be calculated by specialist software using the guidance in BR497, which summarises International Standard ISO 10211:2007. Where details have not been calculated and ACDs are not used, the punitive default values must be applied. The voluntary and more stringent Passivhaus standard aims for effectively thermal bridge free construction, defined as a  $\Psi$  value of 0.01 W/mK or less (BRE, 2011).

Strawbale building in the UK has largely followed variations of the system outlined by Barbara Jones (Jones, 2009) which is popular with self-builders. Heat flows through the construction details used appear not to have been published, so their thermal performance has been unknown. Energy assessments of such dwellings have relied on default  $\Psi$  values, impacting on their accuracy. This paper explores the extent of thermal bridging through standard strawbale construction details containing timber elements, as constructed by Straw Works Ltd, and compares the results to requirements for both UKBR for dwellings, and Passivhaus standards. Additionally it explores simple ways to improve the thermal performance of some details, and reports on thermographic survey of the analysed details as built in a strawbale house. The results should be of interest to strawbale builders, with window and door details in particular also having relevance for timber construction as they concern thermal bridging through installation into timber openings.

### **Window installation thermal bridges**

The literature focuses on thermal bridges caused by window installation, highlighting principals of installation geometry and insulation that affect the amount of additional heat flow through them.

Cappelletti *et al.* (2011) calculated  $\Psi$  for different window installations in clay-block cavity walls. They found the lowest  $\Psi$  values when the outer face of a window is flush with the inner edge of wall insulation, when insulation is continued across the outer face of the window frame, and when insulation is placed beneath the internal sill. A combination of the three results in the lowest  $\Psi$  value.

Ibrahim *et al.* (2014) calculated that window offset thermal bridges contributed 2 to 8% of the total energy demand for a building. By insulating the external faces of the window reveal and frame (with 1 to 2cm of a silica-aerogel coating) the thermal load was reduced by 24 to 50%.

Looking at window installation in strawbale walls, Semenysin (2013b) found that insulating the external faces of the window jamb and the adjacent section of window frame reduced the  $\Psi$  value by 69%. Exploring different positions of window installation in a solid brick wall with strawbale external wall insulation (EWI), the lowest  $\Psi$  resulted from installation in the centre of the strawbale EWI layer (Semenysin, 2013a).



## ***Strawbale thermal conductivity and density***

Various values are reported in the literature for the thermal conductivity ( $\lambda$ ) of strawbale, but some agreement emerges from tests most resembling conditions in a strawbale wall, with monitored moisture content at around 13%.

Tests of a plastered strawbale wall reported by Stone (2003) found a whole-wall  $\lambda$  of 0.099 W/mK in a guarded hotbox test and 0.093 from in situ monitoring. Guarded hotbox tests of a similar construction (a ModCell lime-plastered strawbale panel) by Shea *et al.* (2013) also found total  $\lambda$  (including the plaster) of 0.093 W/mK. Further tests on straw samples in a heat flow meter with heated edge guard found a mean  $\lambda$  of 0.064 W/mK at strawbale densities between 107 and 123kg/m<sup>3</sup> (similar to 118kg/m<sup>3</sup> median density of construction bales in Jones (2009) and the 110 to 120kg/m<sup>3</sup> straw density of ModCell panels (Shea *et al.*, 2013)). Goodhew and Griffiths (2005) used a thermal probe in plastered strawbale walls to find a straw  $\lambda$  of 0.067 W/mK. The broad agreement amongst these results backs up Shea *et al.*'s proposal of 0.064 W/mK as a realistic value for strawbale  $\lambda$ .

Despite suggestions that bale density will impact on  $\lambda$  (Atkinson, 2008; Shea *et al.*, 2010), research suggests the effect is small (Wimmer, R. *et al.*, 2000), with just 0.0048 W/mK difference in  $\lambda$  across bales of densities from 63 to 123kg/m<sup>3</sup> (Shea *et al.*, 2013).

## **Method**

### ***Software analysis***

PsiTherm 2014 software was used to calculate  $\Psi$  values of Straw Works' standard construction details for thermal bridges with timber elements, following ISO 10211:2007. Details analysed were: eaves (for two different roof types), intermediate floor/wall junction, lintel, jamb, and sill. The software analyses a 2D sectional model of each detail, with appropriate  $\lambda$  values applied to each material. The finite element method is used to determine total heatflow through the model, in steady-state conditions.  $\Psi$  represents the difference between heat flow accounted for by the U-values of flanking elements, and the total heat flow calculated. Internal dimensions were used to comply with BR 497 and Part L of UKBR.

Critical (minimum) surface temperatures were also calculated, along with the temperature factor at the internal surface (fRsi), which represents the differing internal surface temperature caused by thermal bridging. Results were compared against minimum fRsi requirements for UKBR. Calculations were then repeated using external dimensions as required for testing compliance with the Passivhaus standard.

The default and approved values required for UKBR are defined in The Government's Standard Assessment Procedure for Energy Rating of Dwellings (SAP). Results were compared to the SAP values, and then against the Passivhaus maximum  $\Psi$  value. Improved performance is indicated by lower  $\Psi$  values than SAP or Passivhaus requirements, and higher fRsi values.

Where construction details fell short of these standards (specifically the window and door details) adaptations were proposed to these to improve their thermal performance. Adaptations were designed to be simple, with self-builders in mind. To that end, only 20mm Steico Universal woodfibre board was used as this material is already specified in some of Straw Works construction details.  $\Psi$  and fRsi values of each adapted detail were calculated as above and again compared to SAP and Passivhaus requirements.

Model extents and boundary conditions (surface resistances, and internal and external temperatures) were determined by BR 497 and ISO 10211:2007. These standards also direct where other information should be drawn from. Where encountered,  $\lambda$  of air layers was calculated according to ISO 6946:2007, and the  $\lambda$  of materials were drawn from ISO 10456:2007. Other materials  $\lambda$  relied on manufacturers data – where there was a range of sources a mean value was used. Straw  $\lambda$  used was 0.064 W/mK, as explained above. Material  $\lambda$  values are shown in Figure 1.

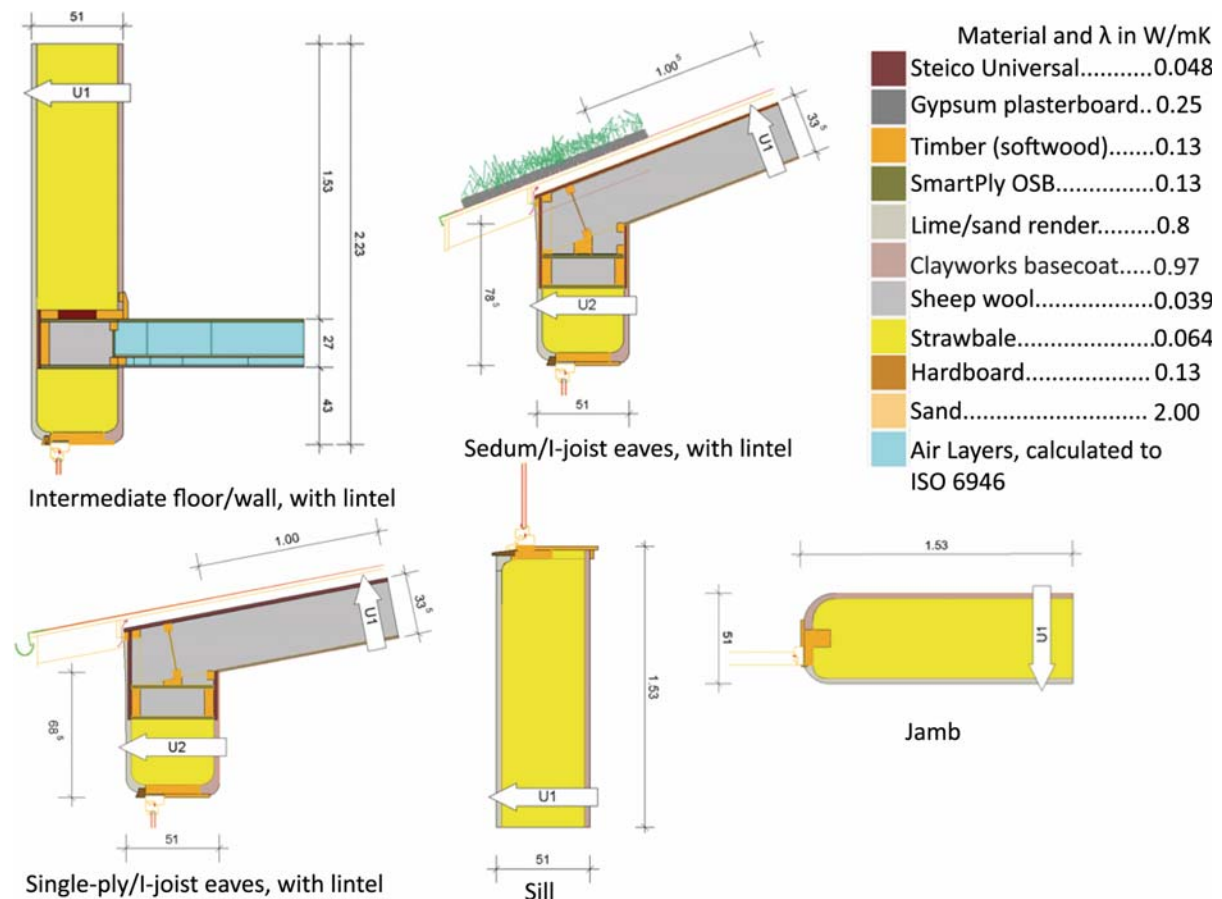


Figure 1. Straw Works construction details, as modelled in Psi Therm thermal bridge calculation software.

## Thermography

A thermographic survey was carried out on a strawbale end-of terrace cottage in Surrey, built using the same Straw Works standard construction details as above. Thermography was directed at points of critical surface temperature and highest heat flux, as indicated by software analysis. Particular attention was given to lintels, jambs and sills. Survey was conducted according to ISO 13187:1999.

Thermal imaging cameras map infrared radiation emitted by an object onto a 2D image representing heat distribution. A calibrated thermal camera was used, with a resolution of 320 x 420 pixels, sensitivity of  $<0.045^{\circ}\text{C}$  and an accuracy of  $\pm 2\%$ . Reflected radiation, relative humidity, ambient temperature, and distance from surveyed object are all entered into the camera which compensates for their impact in its readings. The temperature and humidity meter had a stated accuracy of  $\pm 1^{\circ}\text{C}$  and  $\pm 3\%$  humidity. Reflected radiation was measured once for each building elevation, using the camera and a diffuse mirror (crumpled and then un-crumpled aluminium foil). Distance was estimated.

To ensure a sufficient temperature differential ( $\Delta T$ ) between inside and outside of at least 10 to 15°C the survey was completed in late November 2015, with the property heated. To avoid interference or false readings from solar radiation, the survey was carried out twice: once between 7:30 and 9pm, then repeated between 8:30 and 9:30am. The morning survey was truncated by heavy rain, with external survey being concentrated on window details under a large eaves overhang.

fRsi factors from software analysis were used to calculate predicted minimum internal surface temps ( $T_{si}$ ) according to BR 497, based on internal and external temperatures recorded at the time of survey. FLIR Tools 2.1 was used to identify spot surface temperatures from survey images, allowing comparison with calculated surface temperatures.

## Results and discussion

### Software analysis

Table 1.  $\Psi$  Results for Straw Works standard details, compared to SAP and Passivhaus requirements

	$\Psi$ internal dimensions (W/mK)	SAP $\Psi$ value (W/mK)		Difference from SAP *			
		Approved Value	Default Value	Approved Value	% difference	Default Value	% difference
Eaves: Sedum/I-joist	0.015	0.04	0.08	-0.025	-63.43	-0.065	-81.71
Eaves: Single-ply/I-joist	0.010	0.04	0.08	-0.030	-75.05	-0.070	-87.53
Intermediate floor/wall junction	0.002	0.07	0.14	-0.068	-96.66	-0.138	-98.33
Lintel, under Sedum/I-Joist Eaves	0.033	0.3	1	-0.267	-89.07	-0.967	-96.72
Lintel, under Single-Ply/I-Joist Eaves	0.053	0.3	1	-0.247	-82.27	-0.947	-94.68
Lintel, under First Floor	0.038	0.3	1	-0.262	-87.37	-0.962	-96.21
Jamb	0.051	0.05	0.1	0.001	1.96	-0.049	-49.02
Sill	0.042	0.04	0.08	0.002	4.83	-0.038	-47.59

\* minus number represents improved performance / heat flows lower than the reference standard

	$\Psi$ external dimensions (W/mK)	Passivhaus maximum Psi (W/mK)	Difference from Passivhaus maximum *	
			Passivhaus maximum *	% difference
Eaves: Sedum/I-joist	-0.059	0.01	-0.069	-686.5
Eaves: Single-ply/I-joist	-0.079	0.01	-0.089	-886
Intermediate floor/wall junction	0.002	0.01	-0.008	-76.6
Lintel, under Sedum/I-Joist Eaves	0.034	0.01	0.024	238.5
Lintel, under Single-Ply/I-Joist Eaves	0.053	0.01	0.043	431.9
Lintel, under First Floor	0.038	0.01	0.028	278.9
Jamb	0.051	0.01	0.041	409.8
Sill	0.042	0.01	0.032	319.3

Figure 1 shows the structure of the construction details analysed. Table 1 gives the  $\Psi$  values calculated, compared to SAP and Passivhaus (PH) requirements. All the analysed details perform better than SAP default  $\Psi$  values, but not all perform better than approved details. Intermediate floor/wall junction is the best performing detail, with  $\Psi$  values 98% lower (better) than SAP default value, and 97% lower than the approved value. This detail also narrowly meets the PH requirement, with a  $\Psi$  0.008 W/mK lower than the 0.01 W/mK minimum requirement. Both eaves-types also meet the PH requirement, with  $\Psi$  values 0.089 and 0.069 W/mK lower.

The worst performing details were sill and jamb. Sill  $\Psi$  value is 48% lower than SAP default value, but 5% greater than approved value. Jamb  $\Psi$  is 49% lower than default, but 2% higher than approved value. Although lintel performs 82 to 89% better than approved value (depending on which eaves or floor junction it is installed under) its actual thermal

performance is similar to the jamb and sill: depending on which eaves or floor detail it is installed under, lintel  $\Psi$  ranges from 0.033 W/mK to 0.053 W/mK, with jamb and sill  $\Psi$  falling within the same range. Lintel, sill and jamb would all benefit from improvements to their thermal performance, and all fall short of PH requirements.

Table 2 gives fRsi and critical surface temperatures of the Straw Works standard details, compared to UKBR requirements for buildings such as residential buildings and schools (fRsi 0.75), and for buildings with high humidity such as swimming pools, laundries and breweries (fRsi 0.9). fRsi numbers equal to or higher than these numbers are considered to be unlikely to cause surface condensation.

The best performing details are again the intermediate floor/wall junction with an fRsi of 0.96, and the eaves details with both variants having an fRsi of 0.94, satisfying the criteria for use in high condensation risk buildings. The worst performing detail is sill, which with an fRsi of 0.74 is the only detail that fails to meet even the lower 0.75 fRsi criteria. This confirms that the design of this detail in particular needs to be improved. Jamb (fRsi 0.85) and lintels (fRsi 0.83 to 0.85) meet the lower target but not the higher target for buildings with high relative humidity. These details could also benefit from improved thermal performance.

Table 2. fRsi of standard details, compared to UKBR requirements.

	fRsi	% Improvement over fRsi <sup>1</sup> 0.75	% Improvement over fRsi <sup>2</sup> 0.9	Minimum surface temp
Eaves: Sedum/I-joist	0.9	25.33	5.33	18.74
Eaves: Single-ply/I-joist	0.9	25.33	5.33	18.86
Intermediate floor/wall junction	1	28.00	8.00	19.13
Lintel, under Sedum/I-Joist Eaves	0.9	13.33	-6.67	17.07
Lintel, under Single-Ply/I-Joist Eaves	0.8	10.67	-9.33	16.53
Lintel, under First Floor	0.8	10.67	-9.33	16.53
Jamb	0.85	13.33	-6.67	16.9
Sill	0.7	-1.33	-21.33	14.71

UKBR minimum fRsi to avoid condensation in <sup>1</sup> in residential buildings and schools, <sup>2</sup> in buildings with high humidity, e.g. swimming pools, laundries, breweries

### Adaptations to improve thermal performance

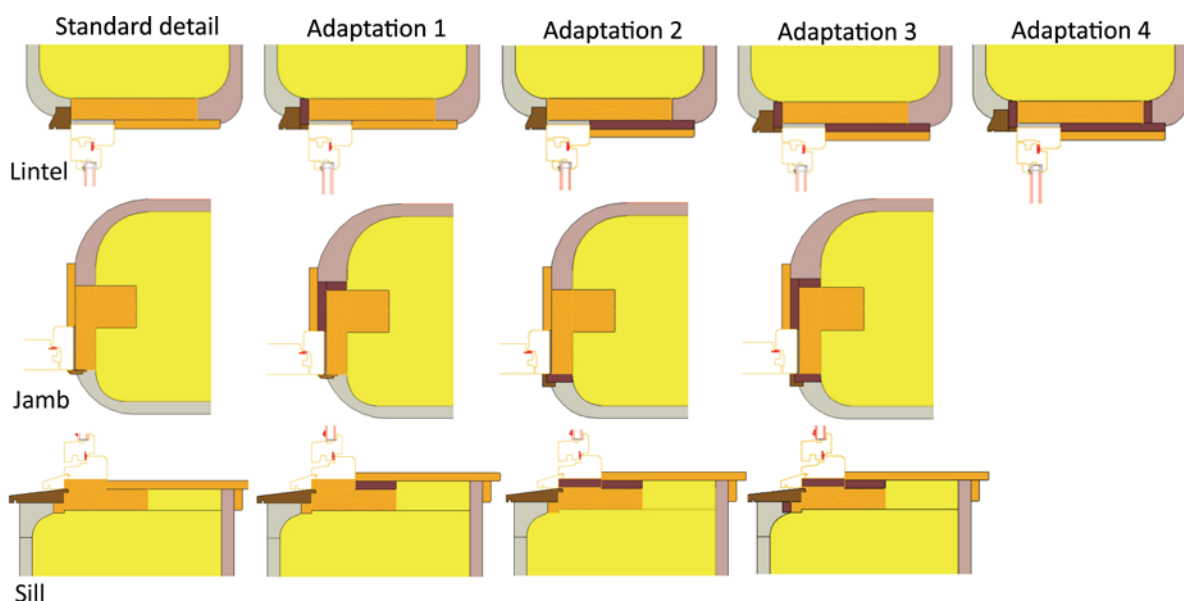


Figure 2. Adaptations modelled to standard details, using additions of 20mm woodfibre board. Legend as in Figure 1.

All the adaptations made revolved around insulating the previously uninsulated faces of structural timbers, using 20mm thick woodfibre board (Figure 2). Adaptations are considered improved if  $\Psi$  values are lower, and  $fR_{si}$  values higher, than the standard detail. In all cases the greatest modelled improvement in thermal performance resulted from insulating all faces of the structural timber.  $\Psi$  results for all adaptations are in Table 3,  $fR_{si}$  results in Table 4. Table 5 compares  $\Psi$  to Passivhaus requirements, for the adaptations with the most improved thermal performance.

Table 3.  $\Psi$  results for adaptations modelled to standard details, compared to SAP requirements.

	$\Psi$ (internal dimensions) (W/mK)	% Improvement over $\Psi$ of standard detail	SAP $\Psi$ value (W/mK)		Difference from SAP (minus number represents improved performance)			
			Approved	Default Value	Approved	%	Default	%
Lintel, under Intermediate Floor	0.038		0.3	1	-0.262	-87.37	-0.962	-96.21
Adaptation 1	0.035	6.86	0.3	1	-0.265	-88.24	-0.965	-96.47
Adaptation 2	0.026	30.69	0.3	1	-0.274	-91.25	-0.974	-97.37
Adaptation 3	0.024	35.89	0.3	1	-0.276	-91.90	-0.976	-97.57
Adaptation 4	0.021	44.29	0.3	1	-0.279	-92.96	-0.979	-97.89
Lintel, under Sedum/I-Joist Eaves	0.033		0.3	1	-0.267	-89.07	-0.967	-96.72
Adaptation 1	0.028	13.800	0.3	1	-0.272	-90.62	-0.972	-97.19
Adaptation 2	0.026	19.836	0.3	1	-0.274	-91.18	-0.974	-97.35
Adaptation 3	0.021	35.421	0.3	1	-0.280	-93.18	-0.980	-97.95
Adaptation 4	0.020	35.704	0.3	1	-0.280	-93.21	-0.980	-97.96
Lintel, under Single-Ply/I-Joist Eaves	0.053		0.3	1	-0.247	-82.27	-0.947	-94.68
Adaptation 1	0.047	16.548	0.3	1	-0.253	-84.36	-0.953	-95.31
Adaptation 2	0.042	30.562	0.3	1	-0.258	-86.13	-0.958	-95.84
Adaptation 3	0.037	43.468	0.3	1	-0.263	-87.76	-0.963	-96.33
Adaptation 4	0.036	44.260	0.3	1	-0.264	-87.86	-0.964	-96.36
Jamb	0.051		0.05	0.1	0.001	1.96	-0.049	-49.02
Adaptation 1	0.041	27.47	0.05	0.1	-0.009	-18.86	-0.059	-59.43
Adaptation 2	0.041	26.29	0.05	0.1	-0.009	-17.96	-0.059	-58.98
Adaptation 3	0.030	55.21	0.05	0.1	-0.020	-39.88	-0.070	-69.94
Sill	0.042		0.04	0.08	0.002	4.83	-0.038	-47.59
Adaptation 1	0.033	24.76	0.04	0.08	-0.007	-18.63	-0.047	-59.31
Adaptation 2	0.028	36.13	0.04	0.08	-0.012	-29.40	-0.052	-64.70
Adaptation 3	0.026	41.28	0.04	0.08	-0.014	-34.28	-0.054	-67.14

### Lintel

Adaptations to lintel were modelled as installed under the two eaves-types, and intermediate floor/wall junction. Installed under sedum/I-joist eaves, lintel with woodfibre board added to the three previously uninsulated faces had a 38% improvement over the  $\Psi$  of the standard detail, and 88% improvement over the SAP approved  $\Psi$  value. Installed under Single-ply/I-joist eaves the same adapted lintel showed a 32% improvement over the standard detail, and a 96% improvement over the SAP approved value. Installed under intermediate floor/wall junction it showed a 44% improvement over the standard detail  $\Psi$ , and 93% over the approved value. It still falls short of the PH requirement by between 0.011 and 0.029 W/mK.

The greatest improvement for a single measure results from insulating the underside of the lintel internally. Under sedum/I-joist eaves this gives a 19% improvement in  $\Psi$  over the standard detail, and 91% improvement over approved value. Under single-ply/I-joist eaves this gives 22% improved  $\Psi$  over standard detail, and 86% over approved value. Under



intermediate floor/wall junction it gives a 31% improvement in  $\Psi$  over the standard detail, and 91% improvement over the approved value.

Insulating just the underside of the lintel internally improves fRsi to the 0.9 fRsi standard for high condensation risk buildings (in all installation situations given above) (0.9 to 0.91 fRsi). Adding woodfibre board to all three previously uninsulated faces of the lintel gives fRsi of 0.91 to 0.95.

Table 4. fRsi results for adaptations modelled to standard details, compared to UKBR requirements.

	fRsi	% Improvement over fRsi <sup>1</sup> 0.75	% Improvement over fRsi <sup>2</sup> 0.9	Minimum surface temp
Intermediate floor/wall junction	0.8	10.67	-7.78	16.53
Adaptation 1	0.8	10.67	-7.78	16.66
Adaptation 2	0.9	20.00	0.00	17.8
Adaptation 3	0.9	20.00	0.00	18.05
Adaptation 4	1	26.67	5.56	19.07
Lintel, under sedum/I-joist eaves	0.85	13.33	-5.56	17.07
Adaptation 1	0.86	14.67	-4.44	17.13
Adaptation 2	0.91	21.33	1.11	18.23
Adaptation 3	0.92	22.67	2.22	18.4
Adaptation 4	0.92	22.67	2.22	18.38
Lintel, under Single-Ply/I-Joist Eaves	0.8	10.67	-7.78	16.53
Adaptation 1	0.8	12.00	-6.67	16.83
Adaptation 2	0.9	20.00	0.00	17.96
Adaptation 3	0.9	21.33	1.11	18.12
Adaptation 4	0.9	21.33	1.11	18.1
Jamb	0.85	13.33	-5.56	16.9
Adaptation 1	0.9	20.00	0.00	18.06
Adaptation 2	0.9	14.67	-4.44	17.26
Adaptation 3	0.9	21.33	1.11	18.23
Sill	0.74	-1.33	-17.78	14.71
Adaptation 1	0.8	12.00	-6.67	16.76
Adaptation 2	0.9	16.00	-3.33	17.4
Adaptation 3	0.9	16.00	-3.33	17.48

### *Jamb*

Insulating the three previously uninsulated faces reduced  $\Psi$  by 41% compared to the standard detail, and 40% compared to the approved value. The smaller improvement over the approved value (compared to the improvement for lintel) is due to the high  $\Psi$  approved value that SAP allows for lintels.  $\Psi$  calculated with external dimensions for PH falls short of PH requirements by 0.023 W/mK.

The single measure that gives the most improvement is insulating the external face of the timber jamb. This gives a 20% improvement over the standard detail, and 18% over the approved detail. It also increases the fRsi sufficiently to allow use in high condensation risk areas.

### *Sill*

Insulating the external vertical face of the structural sill is complicated by the need to securely attach a timber rain-shedding external sill to it. It is possible to insulate the part of the external face that remains exposed, but to limited effect.

Biggest improvement in sill  $\Psi$  values results from insulating the entire upper face of the structural sill (including between it and the window frame) and as much external face as possible. This gives a 37% improvement over the standard detail and 34% improvement over the SAP approved value. It misses the PH requirement by 0.019 W/mK.

Insulating only the internal upper face of the structural sill gives a 22% improvement over the standard detail, and 19% improvement over the approved value.

fRsi increases to 0.84 by insulating the sill internally only, and insulating all faces gives an fRsi of 0.87. This brings the sill detail within the minimum UKBR requirement for dwellings and schools, but still falls short of the requirement for areas of high relative humidity.

Table 5. External dimension  $\Psi$  results for most thermally-improved details, compared to Passivhaus requirements

	$\Psi$ (external dimensions) (W/mK)	Passivhaus maximum $\Psi$ (W/mK)	Difference from Passivhaus maximum	% difference
Lintel, under intermediate floor, Adaptation 4	0.024	0.010	0.014	138.6
Lintel, under Sedum/I-Joist Eaves, Adaptation 4	0.021	0.010	0.011	114.1
Lintel, under Single-Ply/I-Joist Eaves, Adaptation 4	0.039	0.010	0.029	291.7
Jamb, Adaptation 3	0.033	0.010	0.023	228.1
Sill, Adaptation 3	0.029	0.010	0.019	190.4

### Thermography

The construction details were surveyed twice, once in the evening, once in the morning. Temperature ranges described below were observed across both surveys. Internal temperature was 19°C for both surveys. External temperature was 4°C in the evening and 8°C in the morning (giving  $\Delta T$  of 15°C in the evening and 11°C in the morning). Relative humidity for the evening survey was 46% indoors and 76% outdoors (with low wind speed and no rain), and for the morning 50% indoors and 90% outdoors (with rain and strong wind). Table 6 shows minimum surface temperatures derived from the fRsi factors from software analysis. Figure 3 show examples of survey images.

Table 6. Predicted Tsi derived from observed internal and external temperatures at time of survey.

	fRsi	Evening survey			Morning survey		
		T <sub>i</sub>	T <sub>e</sub>	Minimum surface temperature	T <sub>i</sub>	T <sub>e</sub>	Minimum surface temperature
Eaves: Sedum/I-joist	0.94	19	4	18.1	19	8	18.34
Eaves: Single-ply/I-joist	0.94	19	4	18.1	19	8	18.34
Intermediate floor/wall junction	0.96	19	4	18.4	19	8	18.56
Lintel, under Sedum/I-Joist Eaves	0.85	19	4	16.75	19	8	17.35
Lintel, under Single-Ply/I-Joist Eaves	0.83	19	4	16.45	19	8	17.13
Lintel, under First Floor	0.83	19	4	16.45	19	8	17.13
Jamb	0.85	19	4	16.75	19	8	17.35
Sill	0.74	19	4	15.1	19	8	16.14

### Eaves

The surveyed roof was of slate construction, which differs from either of the eaves-types modelled for this paper.

Minimum internal surface temperatures (Tsi) observed at the point indicated by software analysis to be the coldest (confirmed by observations) ranged from 16.2 to 17.4°C, over both surveys. Tsi calculated using fRsi from recorded internal and external temperatures ranges from 18.1 to 18.56°C for eaves, higher than observed in practice. This could be due to inaccuracies in measuring temperature with thermal images, or the effect of additional thermal bridging in three dimensions where rafters meet the wall (not accounted for by the 2D analytical model), or may possibly indicate uneven insulation.

$\Delta T$  between coldest thermally bridged spot and homogenous plane of wall is  $0.5^{\circ}\text{C}$ . This suggests there is moderate increased heat flow where expected. Externally there is no sign of additional heat flow at the eaves.

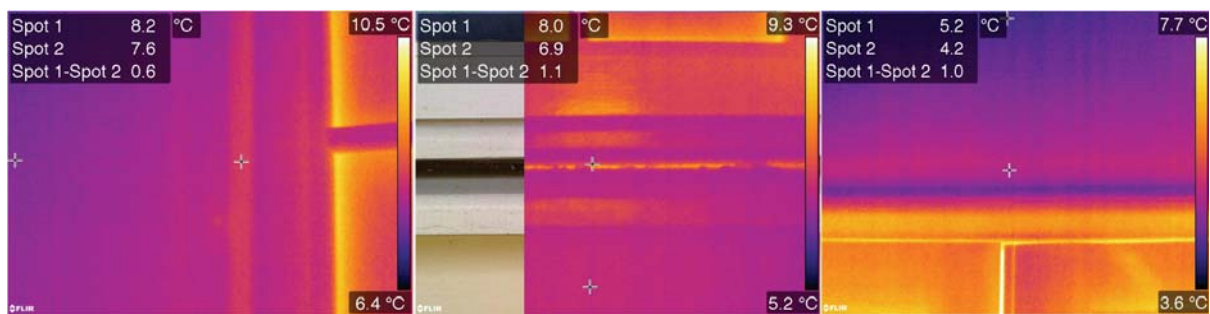


Figure 3. Sample thermal images from survey of window construction details as built. From left to right: jamb, sill, and lintel (all images from external survey – brighter colour indicates greater heat-loss).

### *Intermediate floor/wall junction*

Calculated Tsi are  $18.4^{\circ}\text{C}$  in the evening and  $18.56^{\circ}\text{C}$  in the morning. Observed Tsi range from  $15.4$  to  $19.1^{\circ}\text{C}$ . As with eaves, the lowest temperatures were observed where indicated by software analysis, the  $\Delta T$  from thermal bridge to homogeneous wall was  $0.5^{\circ}\text{C}$ , and no conclusive signs of heat flow were visible externally.

### *Lintel*

Observed Tsi ranged from  $12.3$  to  $17.9^{\circ}\text{C}$ . Calculated Tsi ranged from  $16.45$  to  $17.35^{\circ}\text{C}$  – close to the upper range of observed temperatures, but well above the lowest. Some windows closed tighter than others, so air ingress around the closed section is likely to have affected surface temperatures. There may also be air ingress around the window frame itself. The  $\Delta T$  from thermal bridge to plane of wall ranged from  $1.7$  to  $3.5^{\circ}\text{C}$ , suggesting significant thermal bridging (though exaggerated by air ingress). Thermal images clearly show additional heat flow at the lintel, visible inside and outside.

### *Jamb*

Calculated Tsi is  $16.75^{\circ}\text{C}$ . Observed Tsi ranged  $13.5$  to  $17.1^{\circ}\text{C}$ , with  $\Delta T$  from thermal bridge to plane of wall ranging from  $1.4$  to  $2^{\circ}\text{C}$ . Air ingress through opening section of the window was observed and may have contributed to the lowest temperatures recorded. Ingress around the frame is again possible, but in the absence of a survey conducted with the building depressurised it is hard to confirm. Survey does indicate thermal bridging where software predicted, visible inside and outside.

### *Sill*

Calculated Tsi is  $15.1^{\circ}\text{C}$ . Observed Tsi are  $14.1$  to  $16.1^{\circ}\text{C}$ , the closest to the calculated Tsi observed on any detail.  $\Delta T$  from thermal bridge to plane of wall is  $1.2$  to  $3.3^{\circ}\text{C}$ . Additional heatflow is clearly visible in thermal images, strongly suggesting thermal bridging where software indicated, but as above is also liable to have been affected by air ingress through an imperfect seal between window frame and structural timber sill (airtightness tapes were not used in construction).

The thermographic survey also indicated that heat flow through the window frames themselves is significant.

## **Conclusions**

Software analysis indicates that the Straw Works standard strawbale construction details analysed all perform much better than the default SAP  $\Psi$  values. Energy assessments relying on these values will have overestimated the extent of additional heat flow from the thermal bridging through these details. Thermography found additional heat flow where indicated by software analysis.

Eaves, Lintel and intermediate floor/wall junction all additionally perform significantly better than SAP approved values, though only eaves and intermediate floor/wall junction details meet the Passivhaus requirement for thermal bridging. Eaves and intermediate floor/wall junction also meet the  $fR_{si}$  requirement for buildings with increased condensation risk from high relative humidity. Sill and jamb  $\Psi$  values fall below the SAP approved values. Sill is the poorest performing, as its  $fR_{si}$  value is below the minimum requirement for UKBR. Sill, lintel and jamb could all benefit from improved thermal performance, as evidenced by thermographic survey.

Software analysis of the simple adaptations made to the window and door details indicate that while lintel and jamb details can be improved sufficiently to be safe to use in high condensation risk environments, the sill cannot. All the adaptations will reduce heat flow through the details, but none sufficiently for them to be suitable for use in Passivhaus construction. Together this suggests that a more radical redesign of these details would be beneficial for thermal performance and energy use, with particular attention to the sill. Heatflux images indicate the large structural timbers of lintel, jamb and sill are the main point of heat flow. Reducing the dimensions of these timbers would be one avenue to explore in redesign of the standard details.

Software analysis of redesigned details would provide a clear indication of their likely thermal performance. It would also be useful to collate and analyse different existing designs for strawbale construction details, especially any that have been used in Passivhaus constructions.

## References

- Ascione, F., Bianco, N., Rossi, F. de', Turni, G. and Vanoli, G. P. (2012) 'Different methods for the modelling of thermal bridges into energy simulation programs: Comparisons of accuracy for flat heterogeneous roofs in Italian climates', *Applied Energy*. (Energy Solutions for a Sustainable World - Proceedings of the Third International Conference on Applied Energy, May 16-18, 2011 - Perugia, Italy), 97, pp. 405–418. [Online]. doi: 10.1016/j.apenergy.2012.01.022 (Accessed: 25 September 2017).
- Asdrubali, F., Baldinelli, G. and Bianchi, F. (2012) 'A quantitative methodology to evaluate thermal bridges in buildings', *Applied Energy*. (Energy Solutions for a Sustainable World - Proceedings of the Third International Conference on Applied Energy, May 16-18, 2011 - Perugia, Italy), 97, pp. 365–373. [Online]. doi: 10.1016/j.apenergy.2011.12.054 (Accessed: 26 September 2017).
- Atkinson, C. (2008) *Energy Assessment of a Straw Bale Building*. MSc Architecture: Advanced Environmental and Energy Studies. Graduate School of the Environment (CAT) with University of East London. <http://homegrownhome.co.uk/pdfs/Energyassessmentofastrawbalebuilding.pdf> (Accessed: 23 September 2015).
- BRE (2011) 'Passivhaus primer: Designer's guide. A guide for the design team and local authorities'. BRE Trust. [http://www.passivhaus.org.uk/filelibrary/Primers/KN4430\\_Passivhaus\\_Designers\\_Guide\\_WEB.pdf](http://www.passivhaus.org.uk/filelibrary/Primers/KN4430_Passivhaus_Designers_Guide_WEB.pdf) (Accessed: 25 September 2017).
- Cappelletti, F., Gasparella, A., Romagnoni, P. and Baggio, P. (2011) 'Analysis of the influence of installation thermal bridges on windows performance: The case of clay block walls', *Energy and Buildings*, 43(6), pp. 1435–1442. [Online]. doi: 10.1016/j.enbuild.2011.02.004 (Accessed: 25 September 2017).
- Dixit, M. K., Fernández-Solís, J. L., Lavy, S. and Culp, C. H. (2012) 'Need for an embodied energy measurement protocol for buildings: A review paper', *Renewable and Sustainable Energy Reviews*, 16(6), pp. 3730–3743. [Online]. doi: 10.1016/j.rser.2012.03.021 (Accessed: 25 September 2017).

EU (2010) 'Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010, on the Energy Performance of Buildings (recast)'. <http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32010L0031&from=EN> (Accessed: 25 September 2017).

Evola, G., Margani, G. and Marletta, L. (2011) 'Energy and cost evaluation of thermal bridge correction in Mediterranean climate', *Energy and Buildings*, 43(9), pp. 2385–2393. [Online]. doi: 10.1016/j.enbuild.2011.05.028 (Accessed: 25 September 2017).

Goodhew, S. and Griffiths, R. (2005) 'Sustainable earth walls to meet the building regulations', *Energy and Buildings*, 37(5), pp. 451–459. [Online]. doi: 10.1016/j.enbuild.2004.08.005 (Accessed: 25 September 2017).

Hammond, G. and Jones, C. (2011) 'Inventory of Carbon and Energy (ICE)'. Sustainable Energy Research Team (SERT) Department of Mechanical Engineering University of Bath, UK. <http://www.circularecology.com/embodied-energy-and-carbon-footprint-database.html> (Accessed: 25 September 2017).

Ibrahim, M., Biwole, P. H., Wurtz, E. and Achard, P. (2014) 'Limiting windows offset thermal bridge losses using a new insulating coating', *Applied Energy*, 123, pp. 220–231. [Online]. doi: 10.1016/j.apenergy.2014.02.043 (Accessed: 25 September 2017).

Jones, B. (2009) *Building with straw bales: a practical guide for the UK and Ireland*. Totnes: Green Books.

Mao, G. and Johannesson, G. (1997) 'Dynamic calculation of thermal bridges', *Energy and Buildings*, 26(3), pp. 233–240. [Online]. doi: 10.1016/S0378-7788(97)00005-4 (Accessed: 25 September 2017).

Martin, K., Campos-Celador, A., Escudero, C., Gómez, I. and Sala, J. M. (2012) 'Analysis of a thermal bridge in a guarded hot box testing facility', *Energy and Buildings*, 50, pp. 139–149. [Online]. doi: 10.1016/j.enbuild.2012.03.028 (Accessed: 25 September 2017).

NBS (2014) *The Building Regulations 2010. Approved document L1A, Conservation of fuel and power in new dwellings, 2013 edition*. National Building Specifications Ltd. [http://www.planningportal.gov.uk/uploads/br/BR\\_PDF\\_AD\\_L1A\\_2013.pdf](http://www.planningportal.gov.uk/uploads/br/BR_PDF_AD_L1A_2013.pdf) (Accessed: 25 September 2017).

Semenysin, D. (2013a) *Software Modelling Report - The Influence of a Window's Position in a Wall on the Window's U-value. Strawbale Wrap Brestovec, Slovakia*. <http://www.strawleonardo.eu/wp-content/uploads/2013/07/report-BRESTOVEC-v1.2.pdf> (Accessed: 25 September 2017).

Semenysin, D. (2013b) *The Influence of a Window's Installation on the Window's U-value. A case study with software modelling: FASBA, Germany*. European Learning Partnership for Professional Training in Straw Bale Building. <http://www.strawleonardo.eu/wp-content/uploads/2013/07/report-FASBA-v1.1.pdf> (Accessed: 25 September 2017).

Shea, A., Beadle, K. and Walker, P. (2010) 'Dynamic Simulation and Full-scale Testing of a Pre-fabricated Straw-bale House', in: *International Conference on Sustainable Built Environment (ICSBE-2010)*, Kandy. <http://dl.lib.mrt.ac.lk/handle/123/9222> (Accessed: 25 September 2017).

Shea, A., Wall, K. and Walker, P. (2013) 'Evaluation of the thermal performance of an innovative prefabricated natural plant fibre building system', *Building Services Engineering Research and Technology*, 34(4), pp. 369–380. [Online]. doi: 10.1177/0143624412450023 (Accessed: 25 September 2017).

Stone, N. (2003) 'Thermal Performance of Straw Bale Wall Systems'. [http://naturalbuildingcoalition.ca/Resources/Documents/Technical/thermal\\_performance.pdf](http://naturalbuildingcoalition.ca/Resources/Documents/Technical/thermal_performance.pdf) (Accessed: 24 September 2015).

Theodosiou, T. G. and Papadopoulos, A. M. (2008) 'The impact of thermal bridges on the energy demand of buildings with double brick wall constructions', *Energy and Buildings*, 40(11), pp. 2083–2089. [Online]. doi: 10.1016/j.enbuild.2008.06.006 (Accessed: 25 September 2017).

Wimmer, R., Hohensinner, H. and Janisch, L. (2000) 'Heat Insulation Performance of Straw Bales and Straw Bale Walls'. GrAT (Center for Appropriate Technology) Vienna University of Technology. [http://naturalbuildingcoalition.ca/Resources/Documents/Technical/heat\\_insulation\\_performance\\_strawbales.pdf](http://naturalbuildingcoalition.ca/Resources/Documents/Technical/heat_insulation_performance_strawbales.pdf) (Accessed: 21 November 2014).



# Contemporary earth construction of Saudi Arabia: A state of art review

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**Abstract:** According to the Central Department of Statistics and Information of the Saudi Arabia (the census carried out in 2009), more than 40% of the Saudi families do not own houses, and the rate is increasing. There are many reasons that are contributing in the increment of rate of not owning a house, such as, the increasing price of conventional construction materials, government (through municipalities) limits the construction material for the residences to only steel, fired brick and reinforced concrete. Construction Cost Index of Engineering Cost Record has increased from 0.98 (98%) to 1.25 (125%) between 2000 and 2007 in Saudi Arabia. The main reasons of the government restriction on other alternative construction material such as stabilized rammed earth (SRE) include ambiguity of the structural capability and lack of evidence of environmental benefit. The development of an alternative local construction material could be highly beneficial to the Saudi Arabia in its pursuit toward affordable and sustainable house construction. Based on existing international evidences, utilizing SRE construction technology could lead to saving in the construction cost and maximizing environmental benefit compared to the conventional construction materials. But, literature review reveals that there is sparse research to date carried out to find out why are the potentialities of SRE construction not recognized in Saudi Arabia. The aim of this article is to appraise current state of art review of contemporary earth construction in Saudi Arabia formulating a research agenda. Furthermore, to achieve the aim, author adopts the desktop survey method of critically reviewing and analysing relevant literature to back the arguments of this paper.

**Keywords:** Stabilized earth construction, alternative construction material, environmental sustainability.

## Introduction

According to Babsail & Al-Qawasmi (2015), in the past six decades or so, Saudi Arabia has gone through immense changes in the economic, social and the physical environment as a result of the dramatic increase in national income that has come with the development of the oil industry. Before the first economic boom in Saudi Arabia (till mid twentieth century) that was resulted from the oil discovery and production, different regions in the country were mainly building their homes utilizing locally available construction material such as earth and stone (Babsail & Al-Qawasmi, 2015). According to Mubarak (1999) in 1968 Riyadh had 46% residential buildings constructed with earth compared to 34% built with cement block and concrete; but by 1992, the percentage of residential buildings constructed out of earth was dropped down to 1%. During the past three decades, there has been a construction boom in the cities in the Arabian Gulf area (Babsail & Al-Qawasmi, 2015; Alshammari & Hamid, 2016). Particularly, in eastern province of Saudi Arabia, enormous development programs including new industrial areas establishment, widening of petrochemical facilities, highways and airports construction, and considerable urbanization in the whole area (Alshammari & Hamid, 2016). The extensive adoption of modern technologies, urbanization, rapid development and modernization has resulted in major social and economic transformation in the Saudi society (Babsail & Al-Qawasmi, 2015). Saudis have abandoned adobe and Adobe Architecture nowadays has unfortunately come to be identified with poor rural communities and a sign of backwardness, primitiveness and poverty (Mortada, 2016). On the other hand success stories of the contemporary earth construction projects in India, Australia, Mexico, France and Germany convey a positive message on the earthen architecture and construction to all societies including Saudi Arabia especially the developing countries with shortage of affordable and environmentally sustainable housing. The aim of this article is to highlight

current state of art review of contemporary earth construction in Saudi Arabia and through the critical review of the literature it will be established that earth construction potentially can solve a number of problems prevailing in Saudi Arabia such as, housing shortage, environmental pollution, lack of cultural identity, and loss of architectural heritage, etc.

### Historical background of native earth construction in Saudi Arabia

According to Mortada (2016), construction in adobe or sun-dried mud bricks in Arabia is ancient (King, 1998) and was commonly used in pre-Islamic times in Yemen and Saudi Arabia. The Prophet Muhammad used mud brick (libin) for his residence and mosque in Medina in AD 622 (Mortada, 2016; King, 1998). According to King (1998) mud is used throughout central Arabia Najd, in both the sand desert areas and in the fertile valleys, much of the interior of Yemen and Oman, also extends northwards into Iraq and the Syrian Desert. Therefore traditionally earth construction is not a new phenomenon and culturally Arab population is attached and familiar living in the various form of earth shelters.

According to King (1998), in the recent past presence of earth buildings in the central Arabian tows has a long ancestral relation that is proved by the excavations at Al-Rabadha on the western edge of Najd. The buildings in this excavation were found used sun-dried earth blocks from the centuries preceding Islam through to Abbasid times. The earth walls were extremely hard and the unfired blocks were durable like cement brick (King, 1998). The resilience of mud was demonstrated in extreme terms at Al-Rass in al-Qasim in Najd in 1817, where the 'yellow earth' of the town walls was bombarded with 30,000 rounds by Ibrahim Pasha's massed artillery over a period of three months (Sadleir, 1977). The adhesive quality of the mud was such that the cannon balls had no effect on the defenses according to Sadleir (1977). Similarly, the earth walls built by the Al Rashid at Ha'il in Northern Najd were so strong that they resisted the efforts by Saudi artillery to shatter them in 1921 and they were only demolished some three decades ago (King, 1998). Saudi Arabia is a country with various topographies and climatic regions; therefore, has a number of native earth construction styles that vary among regions. It is, therefore, essential to document earth buildings and construction in Saudi Arabia in a comprehensive way. However, to summarize earth construction and its general styles and material based on regional native architecture in Saudi Arabia, the following is noted in Table 1:

Table 1. Earth construction methods and forms of regional native architecture in Saudi Arabia. Source: Author.

Regions	Earth construction styles and Methods
Central	Unfired hand-made mud-bricks stabilized with hay straws built into load-bearing walls that are finished smooth by application of mud plaster
Eastern	Coral aggregates taken from the shallow beds of the Arabian Gulf. The structure is like skeleton and the walls are typically plastered and whitewashed.
Southern	Rough-cut stones, and rammed earth construction (load-bearing walls) with layers of slate lines to protect the wall surface from common rains of the area.
Western	Skeleton walls with stone construction that are washed white.

The following Figures 1 and 2 offer an easy to read visual information on main types of regional styles of native architecture whereby the use of earth material is common and prominent:

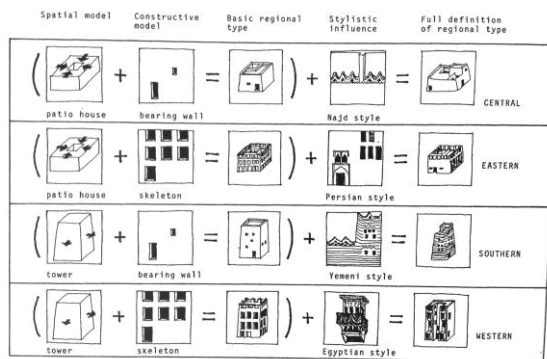


Figure 1. The basic equations for Saudi Native Architecture. Source of the Figure 1 & 2: Ishteeque and Al-Said, 2008.

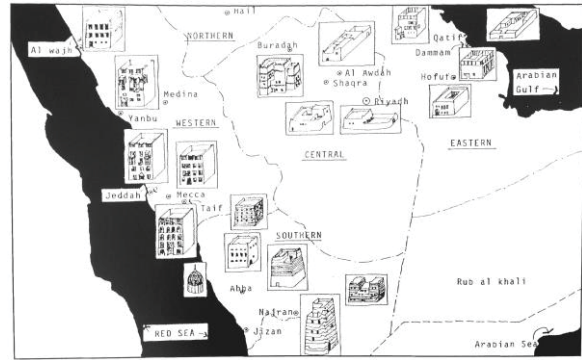


Figure 2. The main regional styles of Native Architecture. Source of the Figure 1 & 2: Ishteeque and Al-Said, 2008.

It is understood from this section that earth construction is historically well known and practiced by the Saudi Arabian people and they are familiar living in shelters constructed out of earth. Having understanding the historical background of earth construction in Saudi Arabia it is pertinent to know whether methods of it is in practice all over the country. Therefore the following section is going to investigate the contemporary earth construction in Saudi Arabia.

### Contemporary earth construction in Saudi Arabia

According to Babsail & Al-Qawasmi (2015), as part of the efforts to revive local traditions, there has been some attempts to expand the use of local materials such as sand, mud and stone. In these contemporary attempts, mud has been used as construction material or as finishing material. However, the exterior facades of the building are finished with mud to give it a traditional appearance. Furthermore, since mud tends to erode badly with rain, in many cases it would be sprayed with a thin coating of transparent polymer to make it waterproof (Babsail & Al-Qawasmi, 2015). The drawbacks of earth material in construction always comes out prominent in the event of all kind of natural disasters such as excessive rain and flood, storm and earthquake. Figure 3, 4, and 5 showing the seismic, storm, and flood areas respectively of the world; accordingly Saudi Arabia is not within all these natural disaster areas. From the above review of the literature, it can be posited that earth construction and building is safe in terms of natural disasters in Saudi Arabia.

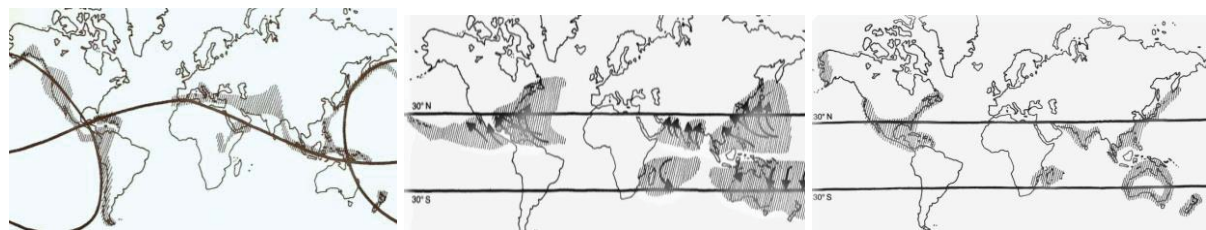


Figure 3 : Seismic regions of the world. Figure 4: Storm regions of the world. Figure 5. Flood regions of the world. Source of the Figure 3, 4 & 5: Houben and Guillaud, 1989.

Adobe buildings have excellent qualities of sustainability; they are environmentally, economically and socially effective (Mortada, 2016). According to King (1998), apart from its resilience and its ready accessibility, the insulating qualities of mud make it an appropriate building material for the environment of central Arabia. Thick mud walls keep the rooms cool in summer, particularly on the ground floor where they were up to a meter thick, narrowing as they rose. In winter, when Najd can experience bitterly cold nights over a prolonged period

of time, the thermal qualities of the mud allow the rooms to retain heat (King, 1998). According to Babsail & Al-Qawasmi (2015), in Saudi Arabia, the efficient use of the earth's resources is not a luxury, but a necessity. Four fifths or more of the country is barren desert. Scarce water resources and a population which is one of the fastest growing of the world make the region most vulnerable to climate change. Work with mud needs skills that have disappeared since long time. To build local capacity, Al-Turath Foundation has conducted continuous training programs to train skilled workers in mud construction (Babsail & Al-Qawasmi, 2015).

Addiriyah is one of the most prominent earthen architectural heritages of Saudi Arabia amongst hundreds of rich heritage sites (Zami, 2014). It is located on the banks of the Wadi Hanifah elevated 700 m above sea level at Najd central plateau of the Arabian Peninsula. The architectural heritage of Addiriyah is taken care by the government of Saudi Arabia and they launched a large-scale program to restore this rich earthen architectural heritage. The development of Addir'iyah Program includes historic villages and neighborhoods along the west to east of the valley including Qasiba, Al Zahra, Al Zowaihira, Al Bejairi, Al Mlaibeed, on the west bank the Al Turaif Quarter (Ar-Riyadh City Web Site 2014). Wadi Hanifah is the most prominent feature of Addir'iyah. It is also an important geographic element and topographic natural formation within the Najd region. Its natural features, rich fertile soil and water combined with land formation suitable for settlement attracted many tribes throughout the past centuries (Ar-Riyadh City Web Site 2014).

The major building material of Turayf (Figure 6) was sun-dried mud brick. According to Facey (1997, 81) mud construction in Arabia traces back its ancestry to pre-Islamic times (King 1998, 12). The durability of mud walls can vary depending on the quality of the raw materials available, the recipe used by the builder, and the care that is taken preparing the mix. The mud mix used in the recent construction of traditional Najdi buildings, such as the houses built when Turayf was briefly re-occupied in the mid-20th century, seems to be of an inferior quality compared to that used in the early palace construction (Facey 1997, 82). According to King (1998, 159) the essential ingredient of mud bricks is clay, found in natural deposits in the Najd, usually in the presence of ground water. Clay is itself an adhesive and a thick mass of clay will crack and break up when it dries up unless mixes with other materials. Therefore in order to make good mud bricks clay was mixed with fine soil taken from silt deposits in Wadi banks, chopped wheat or barley straw (Facey 1997, 82). After mixing, sometimes by trampling, the mix was then poured into a brick-shaped wooden frame on the ground. The mud bricks were then left in the sun in rows to dry. Alternatively, this mix was used directly for constructing a wall making continuous layers on top of each other. The mix might be left for several hours to "ferment". It was considered that, the longer the mix was left to ferment the better the quality of the building material became. Figure 7 shows a stake of handmade mud bricks following this recipe and used reconstructing various buildings in Turayf. If it was supposed to be used for a mud plaster finish on the completed wall it was left for up to twenty-four hours.

The mud bricks used constructing palaces at Diriyah in the late 18<sup>th</sup> and early 19<sup>th</sup> century was considered fine quality compared to the mud bricks commonly used in the recent past. The mud is rather creamy, with very little gravel, suggesting that only a minimum of fine wadi silt was used to temper the clay. There is hardly any straw in the mix. These observations suggest that the builders wanted to maximize the proportion of clay, for the sake of hardness and durability, and added just enough silt and straw to ensure that the bricks remained crack-free.





Figure 6. General scene of Al-Turaif District entrance.  
Source: High Commission for the Development of Ar-Riyadh (2017).



Figure 7. A stake mud brick used in reconstructing many of the buildings at Addiriyah.  
Source: Author's photograph, 2014.

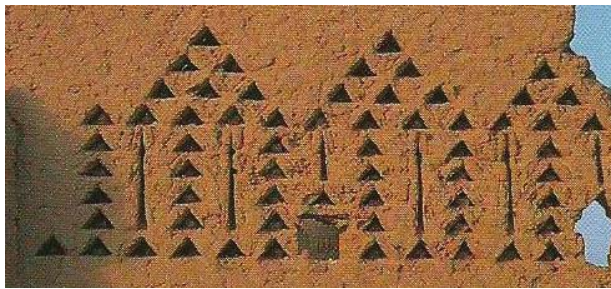


Figure 8. Triangular ventilation openings were found in many of the palaces at Addiriyah. Source: Facey 1997, 80.



Figure 9. Al-Qubba Mosque in Qasr Ibrahim.  
Source: Author's photograph, 2015.

As mentioned earlier the mud bricks were used on top of the stone foundations. At the plinth level wall was very thick, a meter or more, especially if the building was a tall one. For example, the wall thickness of ground floor of Salwa Palace was equal to three mud bricks width, two mud bricks width on the first floor, tapering to one mud brick width on the upper floors. This tapering construction was typical of all Najdi mud walls, and can be clearly seen in the ruins of Turayf palaces (Facey 1997, 83). The buildings were mud plastered once they were nearing completion, and the decorative triangular ventilation openings (Figure 8) were created. According to Cetin (2010), Al Hofuf, also known as Hofuf or Hufuf, is one of the major historical earthen settlements in eastern Saudi Arabia, named as Ash Sharqiyah (or Al Hasa) Province. Hofuf was the capital of the Eastern Province until 1953 and various parts of this old city still contains several landmarks including an old fort known as Qasr Ibrahim from the time of Ottoman Empire controlling the area. Qasr (Castle) Ibrahim was known to be built during Ottoman rule in Al-Hofuf city. It was built in 1556 (963 AH) by Ali Ibn Ahmed Ibn Lawand Al-Burayki, the Ottoman Governor of the time (King, 1986). He also built the Al-Qubba Mosque (Figure 9), which still remains to present day. Qasr Ibrahim combines Islamic and military architecture covering an area of approximately 16,500 square meters and the Saudi Governor Ibrahim Ibn Ufaysan renovated the castle in 1801 AD (Cetin, 2010). The mosque of Al-Qubba which is built inside the fortification wall of the fort contains a large single dome and it is unique in the Kingdom in terms of its construction and style. Built of mud brick and stone covered with a local plaster, the mosque sits on an elevated brick platform within the courtyard of the castle. The south and west walls of the mosque are adjacent to the castle walls, while the north and east walls of the mosque remain open to the courtyard. These north and east walls are treated by a portico of pointed arches supported on large circular columns and roofed by a series of circular domes (Figure 10); some of these arches are decorated with circular lobes (Cetin, 2010).





Figure 10. Domes and arches of The Al-Qubbah Mosque.



Figure 11. Construction system: load bearing mud wall and floor.



Figure 12. Sheet of weaved reed ceilings.

Source of the Figure 10, 11 & 12: Author's photograph, 2016.

According to Warren (1993), Ibrahim palace exhibits unique architectural features and represents typical characteristics of earth architecture. Ibrahim Palace accommodates examples of the unique slab / ceiling system (Figure 11) typical of earth architecture in Saudi Arabia (Ragette, 2003; King, 1986). This system is traditionally based on the accumulation of floor layers starting from circular-sectioned wooden beams and a wooden grid placed on top of these beam with 45 degree angle. Finally, a sheet of weaved reed is laid out on top of this grid and below the actual filling for the floor slab (Stedman & Stedman, 1987). Figure 12 shows this unique system ceiling finish. The ongoing restoration program, however, appears not to see any harm in combining this traditional technique with steel I-section beams under and above the wooden beams despite maintaining the original technique to a great extent throughout the building (Cetin, 2010).

The most recent reconstruction the eastern boundary wall of Qasr Ibarahim was carried out in 2014 and construction technique that was followed is similar to the earth construction technique of Addiriyah reconstruction as explained earlier except the inclusion of mud brick in the wall. In Qasr Ibarahim local lime stone is used as shows in Figure 13 instead of handmade mud bricks. Locally available clay was mixed with fine soil, chopped wheat or barley straw or grass as shown in Figure 14 to prepare the mortar and plaster. The mix was then left for several days with water to ferment as shown in Figure 15. It was considered that, the longer the mix was left to ferment the better the quality of bonding material became. Figure 16 shows how locally available limestone and mud mortar and plaster was used to construction a wall in the recent reconstruction and conservation exercise of Qasr Ibarahim. Figure 17 shows a typical broken wall section that clearly illustrates how was the locally available earth material used to construct a load bearing wall of Qasr Ibarahim.



Figure 13. Local limestone.



Figure 14. Mixed soil with grass.



Figure 15. Earth mixture kept for fermentation under the water.

Source of Figure 13, 14 & 15: Author's photograph, 2014.



Figure 16. A portion of conserved wall using local earth construction.



Figure 17. Typical Earth wall section.



Figure 18. Earth construction is replaced by CMU construction in Qasr Ibrahim.

Source of the Figure 16, 17 & 18: Author's photograph, 2014.

According to Cetin (2010), restoration work of the Qasr Ibrahim in Houfuf represents typical problems regarding the understanding of conservation of architectural heritage in Saudi Arabia and despite the affirmative intentions to preserve history and culture, some concerns regarding materials and techniques of traditional construction seems to be ignored or neglected in various points. In regard to usage of wrong construction materials such as, cement masonry units (CMU) that will crucially misleading or falsifying for future researchers and conservationists. Figure 18 shows a demolished partial structure of typical earth construction inside the Qasr Ibrahim replacing by cement masonry units (CMU) construction in the recent conservation exercise.

According to AlEyadah (2012) the prince Ahmad Bin Salman Mosque (Figure 19) in Riyadh was commissioned by HRH Prince Faisal Bin Salman to serve the Khuzama neighborhood. The construction of this mosque was started on the 28 April 2008 and completed on the 10 August 2010. The mosque covers an area of approximately 1100 sq. m. and 700 worshipers can perform prayer at a time. The ceiling height is 7 meter (Figure 20). The height of the central clearstory ceiling is 8.9 meter and the only minaret height is 16 meter from the ground constructed out of compressed stabilized earth blocks (CSEB) (AlEyadah, 2012). The walls are made out of CSEB on site. A motor driven machine was used to make the earth blocks. To find the appropriate and suitable soil for CSEB the excavation depth reached up to 6.5 meter and the concrete foundation below the wall was a strip foundation; isolated foundations were used below the columns (Figure 21). The exterior CSEB walls of the mosque were constructed starting on top of a .6 meter high wall constructed from locally quarried limestone and cement lime mortar as shown in Figure 22. CSEB was used from .6 meter above the ground level up to the ceiling and the parapet walls were constructed from CSEB and earth mortar as shown in Figure 23.



Figure 19. Exterior view of the mosque.

Source: Explore My Trip, 2017.



Figure 20. Interior columns and ceiling height.

Source: Abdulrahman B., 2016.



Figure 21. Strip and isolated column foundation.

Source: AlEyadah, 2012.



Figure 22. Foundation for the In situ CSEB wall.



Figure 23. Exterior CSEB walls.



Figure 24. Exterior arches were also constructed out of CSEB.

Source of the Figure 22, 23 & 24: AlEyadah, 2012.

Riyadh lime stones were used to construct the columns supporting the ceiling and the columns were square in shape; column head consist of two layers of projected outwards stone courses as shown in Figure 20. The design of these columns resemble to the style of columns of Turayf Palace in Addiriyah as described earlier. The exterior arches along the passageway were also constructed out of CSEB as shown in Figure 24.

It can be posited from this section that earth construction is not a new phenomenon and process in Saudi Arabia and traditionally earth has been in use all over the Arabian Gulf for thousands of years. Contemporary practice of earth construction in Saudi Arabia nowadays is mainly associated with conserving and restoring architectural heritages. The new construction method on stabilized earth construction is also successful and promising for the future construction industry of Saudi Arabia. Therefore, a lot of research and practical experimentation is needed on stabilized earth construction. However being hopeful on the future research it is pertinent to investigate and explore on the availability of earth in Saudi Arabia for construction purposes as literature on appropriate soil for construction are appeared to be very few. The following section therefore investigates the literature on typologies of locally available soil appropriate for earth construction.

### Availability of earth in Saudi Arabia for construction purposes

According to Al-Amoudi, et al (2010) there are four types (i.e., Sand, Marl, Clay and Sabkha) of soil found in eastern Saudi Arabia and Marl is one of the four. Due to the unsuitability of the other three soils, Marl soils are uniquely used in the construction of all types of road bases, embankments and foundations (Alshammari & Hamid, 2016). Marl is defined as a soil or rock-like material containing about 35–65% calcareous material as well as varying percentage of clay content (Netterberg, 1982; Pettijohn, 1975; Qahwash, 1989). According to Ahmed (1995), Calcareous soils, locally known as Marls, are extensively exploited in the construction of highways and building foundations. Despite their wide prevalence all-over the world, a review of the literature indicates that calcareous soils have received little attention from the geotechnical community (Ahmed, 1995). It was found that marl soils are extremely sensitive to the molding and testing moisture contents and chemical stabilization using cement was found to be an effective and efficient way to significantly improve the inferior properties of the Calcareous soils in terms of strength and durability (Ahmed, 1995).

According to Aiban (1995), Marl is abundant in eastern Saudi Arabia in many places such as the Abqaiq, Dhahran, Dammam, Abu Ali, Hofuf, Berri, Fadhli, Jubail, Abu Hadriyah and Safaniyah areas (Figure 25). The Marls in eastern Saudi Arabia vary in terms of their colour, plasticity, physical, mineralogical, chemical composition and also engineering properties. Marl colours varies from one location to another and those include white, dark and light grey, pink, yellow and brown. Marl plasticity varies from none to moderate depending on the



composition, especially the clay mineral type and content (Aiban et al., 1995). Literature review reveal that a number of research was carried out on the chemical stabilization of limited types of Marl and it appears that the compressive strength and durability of Marl significantly improves because of chemical stabilization. But the ongoing research only consider Marls used only for the ground preparation or supporting substructure of the building. Current research in Saudi Arabia do not concentrate at all Marls considered for constructing superstructure of the building such as load bearing wall, column and floor slabs.

In Figure 26 the soil types of Saudi Arabia are roughly classified. According to Beaumont (1976), the Arabian Peninsula is dominated by desert soils, including Lithosols and sand. Lithosol is zonal shallow soil, consisting of imperfectly weathered rock fragments. In general, the characteristics of these soils are: poorly developed soil horizons, very low humus content, predominant direction of the water movement in the soil profile upwards in the Sabkah areas resulting in the accumulation of salts and other soluble products in the upper layers, rocky stony surface layers of pebbles or moving sand soils (dunes). Other soils found that are not specified in the Figure 26 include, Alluvial Soil (Soils in river beds and wadis). This soil sometime is fertile or infertile due to high water tables and salt accumulation in the upper soil layers; sometimes lush vegetation can be found on the higher river banks (Cochrane, 1977). Historically this Alluvial Soil of Wadi Hanifa was used for the construction purposes in the settlement of Addiriyah. Research on modern stabilization technique on this type of soil is inadequate, therefore this needs a long term research commitment and investments how to improve the durability and strength.

Expansive clay soil is available in different areas of Saudi Arabia and traditionally used for vernacular earth houses. There is a study carried out by Hameed (1991) locating of this type of soil in the Eastern Province of Saudi Arabia and its characteristics. The study showed that Al-Qatif and the villages around it, as well as Al-Hofuf and the villages around it are rich in expansive soils. Climate and geology of the area have a big influence on the formation and behavior of expansive soils. Clays in Al-Qatif area are highly plastic, possess very high swelling potential and rich in smectite, illite, dolomite and palygorskite. Al-Hasa clays are plastic, possess moderate to high swelling potential and rich in calcite, illite, palygorskite and kaolinite. A strong correlation between swelling potential and the plasticity of the clay was found in the study.

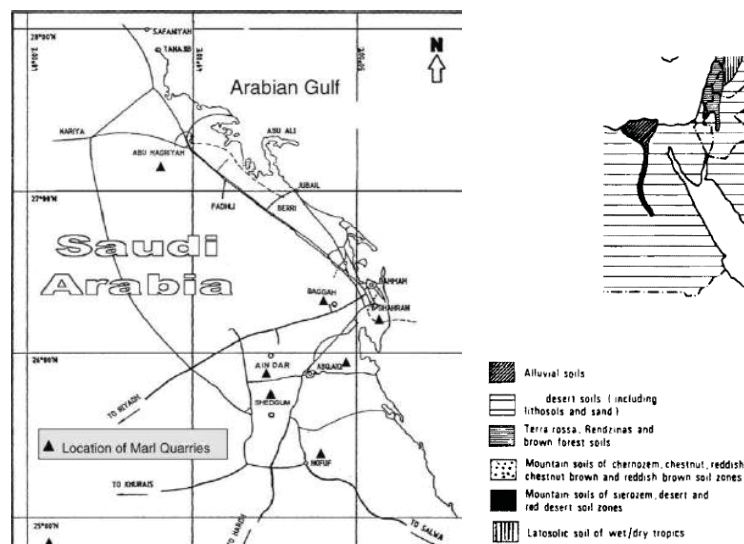


Figure 25. Vicinity map showing locations of major Marl quarries in Eastern Saudi Arabia. Source: Al-Amoudi, et al, 2010.

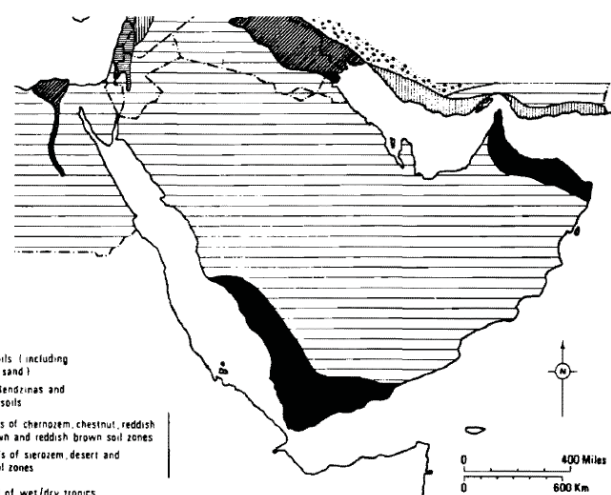


Figure 26. Soil groups of the Middle East. Source: Beaumont, et al, 1976.

According to Hameed (1991), the geology and conditions of the Arabian Peninsula along with observations and laboratory test results indicate that potential expansive soils have probably of occurring. The vast area of the kingdom of Saudi Arabia, with its complicated geological and topographical features makes it difficult with the limited available data to locate all areas of expansive soils. The expansive shale zone includes three major development centres namely Tabuk, Tayma and Al-Ghatt where extreme damage and failures have been reported (Erol and Dhowian, 1990). Expansive soils have also been reported in several other areas, such as, Al-Madina and Al-Hofuf (Dhowian, et al, 1985) and al Qatif area (Abduljawwad and Rafi, 1990). Figure 27 provides an approximate guide to the suspected distribution and extent of potentially swelling soils (Slater, 1983). Furthermore, a study was carried out by Ahmad (1988) concerned with the determination of engineering properties and behaviour of these expansive clays of Qatif by performing various laboratory tests. The results of the experiments showed that Al-Qatif clays are highly expensive, heterogeneous in nature, and 4-8% of commercial lime should be preferred for preconstruction treatment of Al-Qatif clays. According to Ahmad (1988) the regions with expansive soil formations in Saudi Arabia are shown in Figure 28.

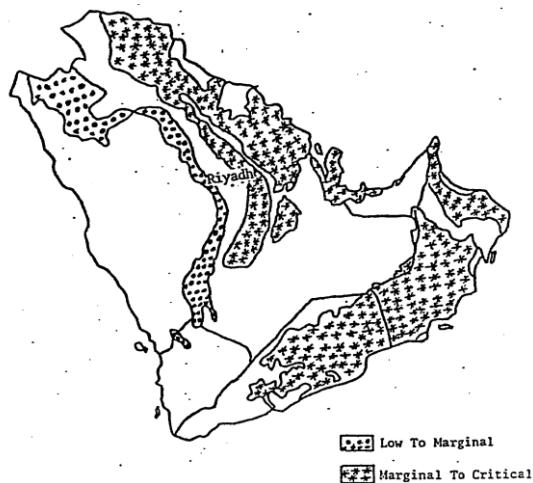


Figure. 27. Hazard map for potentially swelling soils Of Arabian Peninsula. Source: Slater, 1983.

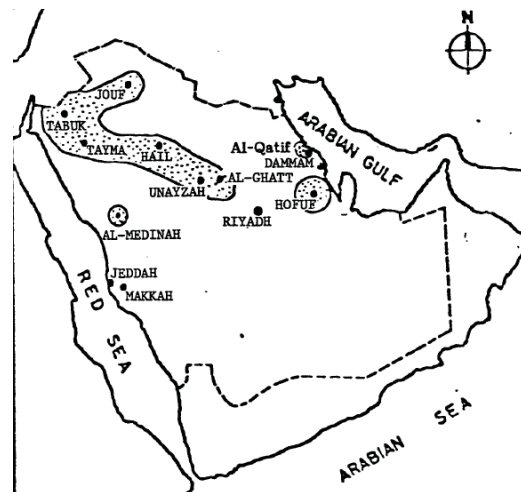


Figure. 28. Tentative Distribution of expansive formations In Arabia. Source: Dhowian, 1985.

However the researches on expansive clays concentrates only for the ground preparation or supporting substructure of the building. Current research on expansive clays in Saudi Arabia do not concentrate on constructing superstructure of the building such as load bearing wall, column and floor slabs.

## Conclusions

This paper has investigated and analysed the existing literature and argued that the adoption of stabilised earth as an alternative material in the construction is appropriate in Saudi Arabian context. In addition, this paper also investigated and explained the different forms of contemporary practice of stabilised earth construction in Saudi Arabian context. It was found out that the application of contemporary stabilised earth as a construction material for the superstructure of the buildings is rare in Saudi Arabia. Current practice of earth construction in Saudi Arabia mainly follows traditional methods for the purpose of conserving and restoring architectural heritages. The new construction method on stabilized earth construction is successful and promising for the future construction industry of Saudi Arabia. Therefore, a lot of research and practical experimentation is needed on stabilized earth



construction. However, research on various indigenous earth samples such as Marl, Alluvial, expansive clay soils are on board but only to use it for the ground preparation of road construction and foundation for buildings. Therefore research and experimentations on load bearing wall, floor slab, and finish material constructed out of stabilised earth is very essential. Research on contemporary stabilized earth construction in Saudi Arabia will open up new avenues to solve several prevailing problems such as, housing shortage, environmental pollution, lack of cultural identity, and loss of architectural heritage, etc. Stabilized earth construction technology is locally available, culturally well known, and environmentally sustainable and would be an appropriate alternative to conventional building materials (fired brick and concrete) in the case of urban house construction in Saudi Arabia.

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## References

- Abduljawwad, S. N. and Rafi, A. (1990). Expansive soil in Al-Qatif Area. The Arabian Journal for Science and Engineering, Vol. 15, No. 2A. <http://www.springer.com/engineering/journal/13369/PSE?detailsPage=press>
- Abdulrahman, B. (2016). Website: Foursquare. <https://foursquare.com/v/%D9%85%D8%B3%D8%AC%D8%AF-%D8%A7%D9%84%D8%A7%D9%85%D9%8A%D8%B1-%D8%A7%D8%AD%D9%85%D8%AF-%D8%A8%D9%86-%D8%B3%D9%84%D9%85%D8%A7%D9%86--prince-ahmed-bin-salman-mosque/53b05fb5498ee976142b292a/photos>, Accessed 25.09.2017.
- Ahmed, Habib-ur-Rehman. (1995). Characterization and stabilization of Eastern Saudi Marls. MSc in Civil Engineering thesis. College of Graduate Studies, King Fahd University of Petroleum & Minerals, Dhahran, Saudi Arabia.
- Ahmad, Rafi. (1988). Engineering properties and mineralogical composition of expansive clays in Al-Qatif area (K.S.A). MSc in Civil Engineering thesis. College of Graduate Studies, King Fahd University of Petroleum & Minerals, Dhahran, Saudi Arabia.
- Aiban, S. A. (1995). Strength and compressibility of Abqaiq marl, Saudi Arabia. Engineering Geology 39 (1995) 203-215, Elsevier Science B.V.
- Aiban, S. A.; Al-Abdul, W. H. I. & Al-Amoudi, O. S. B. (1998). Identification, evaluation, and improvement of Eastern Saudi soils for construction purposes, final report. Riyadh, Saudi Arabia: King Abdulaziz City for Science and Technology (KACST AR-14-61); 1998a.
- Aiban, S. A., Al-Abdul, W. H. and Al-Amoudi, O. S. B. (1995). Identification, evaluation and improvement of eastern Saudi soils for constructional purposes. Progr. Rep. 2 to be submitted to King Abdulaziz City for Science and Technology (KACST AR-14-61).
- Al-Amoudi, O. S. B.; Khan, K.; Al-Kahtani, N. S. (2010). Stabilization of a Saudi calcareous marl soil. Construction and Building Materials 24 (2010) 1848–1854, Elsevier Ltd. journal homepage: [www.elsevier.com/locate/conbuildmat](http://www.elsevier.com/locate/conbuildmat)
- Al-Gunaiyan, K. A. (1998). Assessment of the geotechnical properties of stabilized sand-marl mixtures for constructional purposes. MSc in Civil Engineering thesis. College of Graduate Studies, King Fahd University of Petroleum & Minerals, Dhahran, Saudi Arabia.
- Alshammari, A. M. & Hamid, A. M. (2016). Calcareous Sediment in Saudi Arabia: A Review of Marl Soil. Proceedings of 2016 2nd International Conference on Architecture, Structure and Civil Engineering (ICASCE'16), ISBN 978-93-84422-62-2. London (UK), March 26-27, 2016.
- Al-Eyadah, B. (2012). Prince Ahmad Bin Salman Mosque, Riyadh, Saudi Arabia. LEHM 2012 - 6th International Conference on Building with Earth. Organised by LEHM 2012. Project Team Dachverband Lehm e.V. 5-7 October, Weimar, Germany. [http://www.dachverband-lehm.de/lehm2012/index\\_en.html](http://www.dachverband-lehm.de/lehm2012/index_en.html)
- Al-Amoudi, O. S. B.; Khan, K. & Al-Kahtani, N. S. (2010). Stabilization of a Saudi calcareous marl soil. Construction and Building Materials 24 (2010) 1848–1854. Journal homepage: [www.elsevier.com/locate/conbuildmat](http://www.elsevier.com/locate/conbuildmat)

Ar-Riyadh City Web Site (2014), High Commission for the Development of Ar-Riyadh. [http://www.arriyadh.com/Eng/ADA/Left/DevProj/getdocument.aspx?f=/openshare/Eng/ADA/Left/DevProj/AddiriyaEn093.doc\\_cvt.htm](http://www.arriyadh.com/Eng/ADA/Left/DevProj/getdocument.aspx?f=/openshare/Eng/ADA/Left/DevProj/AddiriyaEn093.doc_cvt.htm) (Accessed 01.03.2014).

Babsail, M. O. & Al-Qawasmi, J. (2015). Vernacular Architecture in Saudi Arabia: Revival of Displaced Traditions. Vernacular Architecture: Towards a Sustainable Future – Mileto, Vegas, García Soriano & Cristini (Eds) © 2015 Taylor & Francis Group, London, ISBN 978-1-138-02682-7.

Beauman, P.; Blake, G.H.; Wagstaff, J. M. (1976). The Middle East a geographical study. John Wiley and Sons; London 1976.

Cetin, M. (2010). Cultural versus Material; Conservation Issues Regarding Earth Architecture in Saudi Arabia: the Case of an Ottoman Fort: Ibrahim Palace in Al-Houfuf. International Journal of Civil & Environmental Engineering 102304-8585-IJCEE-IJENS Vol: 10 No: 04. <http://ijens.org/102304-8585%20IJCEE-IJENS.pdf>

Cochrane, T. (1977). Landscape design for the Middle East"; Riba Publications Limited; London, 1977.

Dhowian, A., Erol, A., Ruwiah, I. (1985). The distribution and evaluation of expansive soils in Saudi Arabia. The second Saudi Engineers Conference, KFUPM, Dhahran, KSA, November 16-19, 1985.

Dhowian, A.; Ruwiah, I.; Erol, A.; Youssef, A. (1985). The distribution of the expansive soils in Saudi Arabia. The second Saudi Engineers Conference, KFUPM, Dhahran, KSA, November 16-19, 1985.

Eshteeaque, E. M.; Said, F. A. (2008). The Native Architecture of Saudi Arabia, Architecture and Identity. Riyadh Municipality, King Fahd National Library, Al Turath, Saudi Arabia.

Explore My Trip (2017). <http://www.exploremytrip.com/location-details/info/MzY3MTk/Prince-Ahmed-Bin-Salman-Mosque>, Accessed 25.09.2017.

Facey, W. (1997). Diriyah and the first Saudi state. Editor: Mark Petre. Stacey International, 128 Kensington Church Street, London.

Hameed, R. A. (1991). Characterization of expansive soils in the Eastern Province of Saudi Arabia. MSc in Civil Engineering thesis. College of Graduate Studies, King Fahd University of Petroleum & Minerals, Dhahran, Saudi Arabia.

High Commission for the Development of Ar-Riyadh (2017). Historical Addiriyah, Development Program. [http://www.ada.gov.sa/ADA\\_e/DocumentShow\\_e/?url=/res/ADA/En/Projects/Addiriyah/index.html](http://www.ada.gov.sa/ADA_e/DocumentShow_e/?url=/res/ADA/En/Projects/Addiriyah/index.html), accessed 19 September, 2017.

King, G. (1998). The Traditional Architecture of Saudi Arabia. I. B. Tauris & Co Ltd, Victoria House, Bloomsbury Square, London.

King, G. R. D. (1986). The Historical Mosques of Saudi Arabia. London & New York: Longman, pp.169-172, 1986.

Mortada, H. (2016). Sustainable Desert Traditional Architecture of the Central Region of Saudi Arabia. Sustainable Development, Sust. Dev. 24, 383–393 (2016). Published online 30 March 2016 in Wiley Online Library. (wileyonlinelibrary.com) DOI: 10.1002/sd.1634.

Mubarak, F. (1999). Cultural Adaptation to Housing Needs: A Case Study, Riyadh, Saudi Arabia, In the IAHS Conference Proceedings, San Francisco, USA.

Netterberg, F. (1982). Geotechnical properties and behavior of Calcretes in South and Southwest Africa, ASTM STP 777. Philadelphia: American Society for Testing and Materials; 1982. p. 296–309.

Pettijohn, F. J. (1975). Sedimentary rock. New York: Harper and Row; 1975.

Qahwash, A. A. (1989). Geotechnical properties of fine-grained calcareous sediments for engineering purposes. Eng Geol 1989; 26:161–9.

Ragette, F. (2003), Traditional Domestic Architecture of the Arab Region, American University of Sharjah (ISBN 3-932565-30-4), Axel Menges Editions. 2003.

Sadleir, G. F. (1977). Diary of a Journey across Arabia (1819) (New York and Cambridge, 1977), p 126.

Slater, D. E. (1983). Potential expansive soils in Arabian Peninsula. Journal of Geotechnical Engineering, ASCE, USA, vol. 109, no. 5, May.

Stedman, M & Stedman, W. (1987). Adobe Architecture, Sunstone Press, Santa Fe, NM, 1987.

Warren, J. (1993). Earthen Architecture: The Conservation of Brick and Earth Structures. A Handbook, ICOMOS, Colombo, 1993.

Zami, M. S. (2014). International Conference on Vernacular Heritage, Sustainability and Earthen Architecture VerSus 2014, 2nd MEDITERRA, 2nd ResTAPIA, 11-13 of September 2014, Valencia, Spain.

# People's perceptions of industrial hemp – understanding attitudes and prejudices towards a sustainable construction material

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**Abstract:** Industrial hemp (IH) is a low-carbon renewable resource which can be utilised for a vast number of applications. One very promising field of application is the construction sector where IH can be used as a sustainable building material e.g. for insulation, as alternative to plaster board or in hemp-lime wall constructions (“hempcrete”). But up to now, hemp-based construction materials suffer a niche existence. To understand the obstacles towards enlarging market uptake, this study aimed at analysing prevailing attitudes towards IH in Europe and to correlate these to the sustainable consumption (SC) attitudes and sociodemographic data of the participants. A survey was conducted as an online survey (N=138, aged between 17 and 64). The general attitudes of the participants of this study towards IH were rather positive, but a large knowledge gap regarding the historical significance and ecological benefits of hemp was revealed. Positive correlations could be found between the knowledge in these areas and the attitude towards IH, as well as the likeliness to purchase IH products. Larger studies are required to further elucidate this subject area.

**Keywords:** industrial hemp, attitudes, sustainable consumption

## Introduction

Hemp is one of the most versatile and eco-friendly crops existing – it is a multi-purpose, non-toxic, renewable and low-impact crop which can be grown in Europe without the use of artificial irrigation or pesticides, and which increases the quality of the soil (Piotrowski and Carus, 2011). Hemp is an extremely versatile resource as its stalk as well as the seeds, flowers and leaves can be utilised for the production of food, textiles, building materials, cosmetics and for natural fibre-reinforced composites (Herer, 1993; Carus 2013). The low-Tetrahydrocannabinol (THC) varieties with THC contents below 0.2 or 0.3% are referred to as industrial hemp (IH).

After its application for thousands of years, the process of industrialisation and the invention of synthetic fibres resulted in the downfall of its commercial usage in the early 20<sup>th</sup> century, but currently, hemp-derived products exhibit slightly growing markets as shown in Figure 1. Despite the tremendous environmental benefits of hemp cultivation described in literature (Herer, 1993; Michka, 1994), the hemp market remains a niche market (Carus, 2013).

One of the most important reasons for that is a lack of knowledge in the broad public, or rather the existence of several prejudices and the mix-up of IH and its high-THC variety Marihuana. Both result from massive propaganda against hemp in the USA in the 20<sup>th</sup> century which will be explored later. As a result of this negative public and political climate for IH, R&D with regard to production and harvesting techniques still remains very limited. Thus, technological innovation and progress is weak compared to other materials. Further reasons why IH has not yet become an important resource for the “green economy” are lower profit margins compared to petro-based materials, the dependency on annual variations and potential shortages due to bad harvests (Carus, 2013). Consequently, the hemp-derived products which are currently available at the market are rather expensive, of limited varieties

and design quality, and difficult to purchase as only available in special shops or via few online retailers.

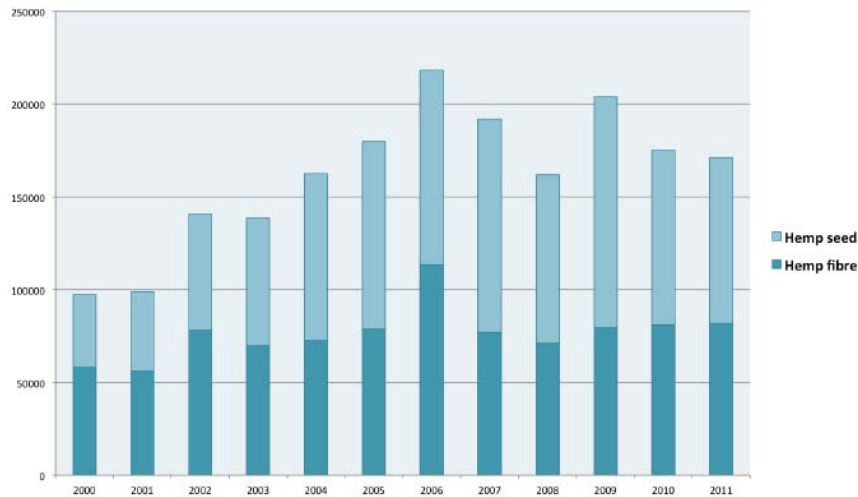


Figure 1: Global production of hemp fibre and seeds in tonnes between 2000 and 2011 (Carus, 2013).

But due to the multitude of environmental problems humanity faces today, a resource which is well-suited to tackle several of these problems should not be overlooked.

As a first step to increase IH usage, the attitudes towards IH need to be investigated. As no current studies on the IH-related attitudes and prejudices in Europe exist, this field of research was chosen for this work. The study was performed online and aimed at evaluating the IH-, and sustainable consumption (SC) related attitudes of European citizens, especially in Germany. The research questions which were investigated are:

- Which are the prevailing attitudes towards industrial hemp?
- What do people know about the ecological benefits and the historical significance of hemp products?
- Is there a correlation between knowledge and attitudes in these areas?

In the following, the topics industrial hemp and attitude formation will be explored. Afterwards, the research methods will be described and the results of the survey will be presented, analysed and discussed.

## Literature Review

### *Industrial Hemp – the “Billion-dollar Crop”*

Hemp was one of the first non-food industrial plants utilised by man. In China, hemp was for instance cultivated about 8000 years ago. Between the 14<sup>th</sup> and the 18<sup>th</sup> century, hemp was introduced into the whole western world and became the dominating fibre crops throughout the world. Hemp has been used for paper, textiles, sails, cordage, or as medicine, as well as in the building industry, especially in France, as archaeologists found old bridges built with a hemp-concrete (Crescini, 1971; Mignoni, 1999).

But during the late 19<sup>th</sup> and early 20<sup>th</sup> century, the process of industrialisation, the availability of cheap, exotic fibres and the invention of new, synthetic fibres resulted in a downfall of the commercial usage of hemp (Carus, 2005; Rhydwen, 2006). While the introduction of machinery resulted in some efficiency gains, political or economic driving forces most likely have prevented a major breakthrough of hemp – which was referred to as the “new billion-dollar crop” at that time (Figure 2, Popular Mechanics, 1938).



Figure 2: Article in the magazine 'Popular Mechanics' run in 1938, only a few months after the criminalisation of hemp in the USA.

The origins of this propaganda against hemp, which was ongoing in the USA and around the world throughout the whole 20<sup>th</sup> century, are diverse and difficult to capture as much has been written which may be considered to fall into the category of conspiracy theory and reliable sources are difficult to find.

These origins may either be of an economic nature, as powerful stakeholders (William Hearst, DuPont) wanted to replace hemp-based products by more profitable synthetic materials, or of a political nature and associated with racism and the fear of immigrants (PBS, 2015; Herer, 1994). In 1937, the US government passed the Marihuana Tax Act and most farmers ceased hemp cultivation due to of various requirements such as a license from the federal drug agency DEA. During the 1930s and 1940s, various anti-drug propaganda movies such as *Reefer Madness* (1936), *Assassin of Youth* (1937) and *Devil's Harvest* (1942) were produced in the USA (Figure 3). Most of them display the dramatic events associated with the use of marijuana. While in the post-war period, the worldwide cultivated area amounted to about 1 million hectares, in the following decades, hemp cultivation was criminalised in almost all European countries (Karus, 2005). In the 1970s, parents' movement against cannabis began as a nationwide movement demanding stricter regulation of cannabis and the prevention of drug use by teenagers (PBS, 2015).

Propaganda against hemp in Europe is hardly documented but as the propaganda movies were also presented in Europe, and due to the generally very high impact of American movies and culture in Europe, a high impact of the US propaganda on European citizens and governments can be estimated. The described propaganda campaigns against hemp resulted in a negative perception of hemp in the general public and the mix-up of industrial hemp with its high-THC variety Marihuana.





Figure 3: Poster of propaganda movies *Reefer Madness* (1936), *Assassin of Youth* (1937) and *Devil's Harvest* (1942) (Hubpages, 2012).

Possibly due to an increasing awareness for sustainability issues, resulting in growing markets for natural products, as well as due to changing EU politics aiming for greater diversity (Mignoni, 1998), IH cultivation has been re-allowed in most European countries in the late 1990s (UK: 1993, Germany: 1996, Sweden: 2003). Also in the United States, cultivation policy is currently changing in several US states.

## Attitudes

### Attitude Formation

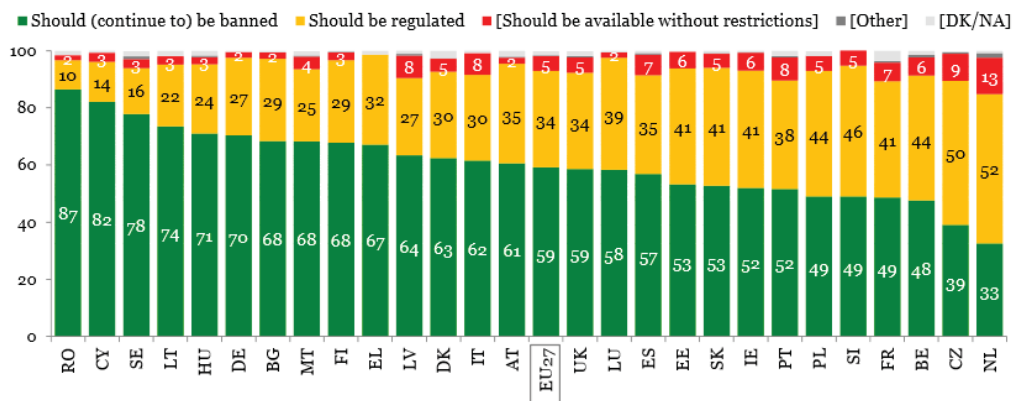
An attitude can be defined as a predisposition of an individual to evaluate some symbol or object or aspect of his world in a favourable or unfavourable manner (Katz, 1960). Attitudes are formed as the result of experience or upbringing and can have a powerful influence over behaviour. According to the tricomponent model, attitudes consist of three components which interact with each other: the cognitive component: thoughts and beliefs about the subject, the affective component: feeling and motions caused by an object, person, issue or event, and the behavioural component: influence of the attitude on our behaviour. (Bem, 1972). Attitudes can either be positive, negative, or uncertain. They can be explicit or implicit, which means that person is either consciously aware of a specific attitude or not (Rudman, 2004). With regard to surveys which aim at the identification of attitudes, these aspects have to be taken into account as direct questions asking for a person's attitude will only reveal explicit attitudes. While various theories on the formation of attitudes exist (Katz, 1960; Jones, no date), the two most important external sources which lead to the formation of our attitudes are peers (Moschis and Churchill, 1978), and the media (McCombs and Shaw, 1972).

### Hemp-related Attitudes in Europe

While discussions in internet forums are plentiful, no published data on IH-related attitudes or prejudices in Europe could be found. One US study could be identified which correlated personal attitudes concerning drug laws and people's willingness to purchase IH products (Baker, no date). In this study, a positive correlation between drug law attitude and willingness to buy IH products could be found.

All other available studies focus on attitudes towards cannabis as a drug, analysing consumption behaviour, perceived health-related danger of consumption, ease of purchase or opinions towards legislation (EC, 2011a). A study carried out by the EC with young citizens aged 15 to 24 in 2011 found that only 5% of the citizens in Europe and 2% of the German citizens think that cannabis should be available without restrictions (Figure 4). When transferring these findings to the results of Baker, the rather negative attitude towards cannabis legalisation in Europe and Germany might be correlated with a low willingness to purchase IH product.

#### Cannabis should (continue to) be banned or regulated



Q7. The sale of drugs such as cannabis, cocaine, ecstasy and heroin is officially banned in all EU Member States. The sale of legal substances such as alcohol and tobacco is not prohibited but is regulated in all EU countries. Do you think the following substances should (continue to) be banned or should they be regulated?  
Base: all respondents, % by country

Figure 4: Opinions of young citizens aged 15 to 24 towards cannabis legislation in the EU (EC, 2011a).

## Methods

The aim of this study was to identify prevailing attitudes and prejudices towards industrial hemp following a mixed approach using secondary quantitative data as well as quantitative and qualitative primary data. In this study, general attitudes towards industrial hemp of people in Europe should be examined and compared to people's attitudes towards SC. To the knowledge of the researcher there is no current study on people's attitudes towards IH. Thus, a pre-survey was performed to determine a baseline for people's attitudes and identify suitable questions as well as multiple-choice answers for the major survey which was performed as an online survey. In this paper, only certain aspects of the major survey are presented and discussed.

### Questionnaire Design

For the construction of the online survey, the website [www.soscisurvey.de](http://www.soscisurvey.de) was used. The complete questionnaire included a total of 20 question pages and seven filter pages were used to limit the questions presented to the participant to those questions, which makes sense based on his prior answers (e.g. "Have you bought hemp products before?" – if answer is yes: "Which products?", if answer is no: "Why not?"). The questionnaire was built in two languages, British and German, and the language could be chosen by the participant on the first page, as many participants were expected to be from Germany and answering a survey in one's mother tongue is regarded to be more precise and easier (Laws et al., 2003). Quantitative and qualitative open and closed questions were included. But in contrast to the pre-survey, most of the open questions were changed into closed, multiple choice questions to facilitate data analysis as sample size was expected to be significantly higher. Thereby, the

bias introduced by giving potential answers to the participants was considered but accepted due to feasibility. Abbott and McKinnney (2013) also describe the advantage of higher efficiency of closed questions regarding the time required to fill out the questionnaire. All multiple-choice questions included the possibility of giving at least one “own answer” via an “others” field with a blank space. As in the pre-survey, the sociodemographic data were collected at the end of the survey to avoid cancellation (Thomas, 2004). The questionnaire was designed for completion within about 10 to 15 minutes to maximise response rate.

### ***Survey Distribution & Data Collection***

As a result of the decision for an online survey as opposed to a larger paper-based survey, only a non-probability sample could be achieved via social media and direct mailings to friends and people involved in the hemp business for further snowballing. Through this mixed convenience and snowballing technique, no representative sample of the European population could be achieved, but rather a relatively young, well-educated sample with strong environmental attitudes.

### ***Response Rate & Participant Demographics***

The sample included 139 people, 96 have completed the whole survey and 91 have revealed their demographic data. These sociodemographic data are shown in Figure 5 - Figure 7. Participant were mainly from Germany (58%), the United Kingdom (9%), Slovenia (8%), Finland (7%) and France (3%) (Figure 5).

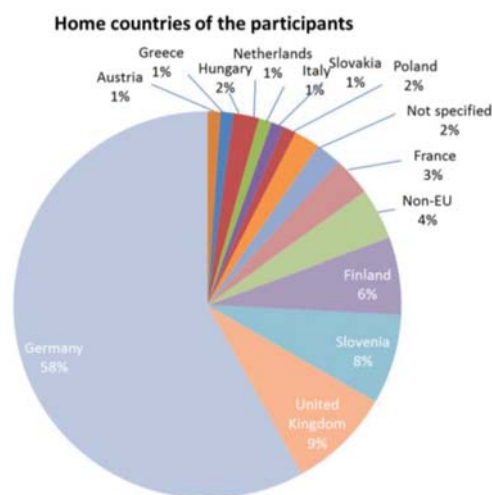


Figure 5: Home countries of the participants.

When asked for their net incomes, 18% of the participants stated that they earn less than 500€ per month, 26% earn 500 to 1000€, 12% earn 1000 to 1500€ and almost 40% stated to earn more than 1500€. Compared to the average income in Germany, these values are slightly lower as about 60% of the German citizens but only 50% of the participants have a net income above 1000€ (Statistika, 2016). The educational background of the participants as determined by the highest level of formal education ranges between “still going to school” (4%), secondary school - 8, 9 or 10 years (7%), secondary school - 12 or 13 years (19%), Bachelor degree (24%), Master or Diploma degree (35%) and PhD or higher (8%). Compared to the general society in Germany, in which 12% have a university degree and only 1% have a PhD (bpb, 2014), the educational background of the participants can be regarded as very high.

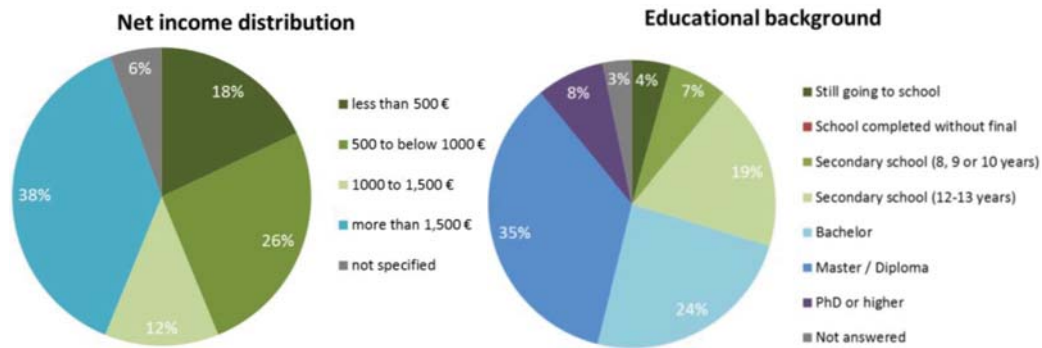


Figure 6: Monthly net incomes (left) and educational background of the participants (highest level of formal education) (right) of the participants.

The age of the participants ranges between 17 and 64 with an average of 34 and a median of 31. Most participants are in the age range 26 to 35 (Figure 7). Compared to the age distribution in Germany, with an average value of 44 and a median of 46 (destatis, 2016; CIA, 2016), the sample of this study is significantly younger. The gender distribution consists of 59% male and 41% female participants and is thus slightly male-biased. When comparing the gender-related age distribution, slightly more young women and old men were included in the sample group.

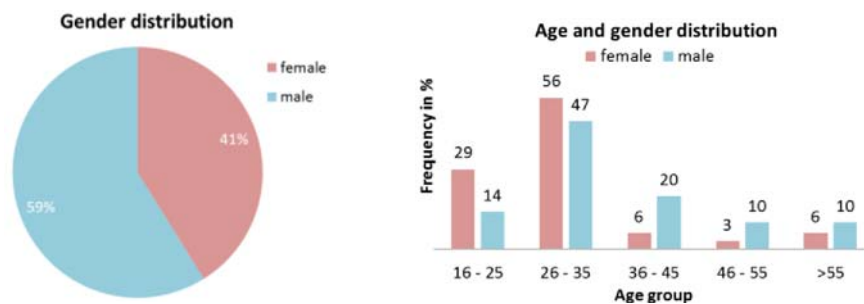


Figure 7: Gender (left) and gender related age distribution (right) of the participants.

## Data Analysis

The collected data were downloaded from the SoSciSurvey website and statistical evaluations and graphical visualisations of the data were performed in Excel. Descriptive statistics were used and Pearson as well as Spearman correlations were calculated for specific data as described by Abbott and McKinney (2013).

## Results

### Consumption Attitudes

The general consumption attitudes of the participants were tested. The results, which are shown in Figure 8 and Table 1, reveal very strong ecological consumption attitudes of the participants. While the aspects of trend and design were stated to have a minor influence on the participant's consumption decisions, the willingness to pay more for more sustainable products is very high (80% agreement). This value slightly exceeds values determined in other studies in Europe (EC, 2014). Also, the aspects "naturalness of a product", as well as "durability" and "regionality" are highly important to the participants (agreement: 76%, 75% and 75%). These values exceed average values in the EU by far, as a 2014 study found regionality and naturalness of products to be considered important by only 22% of the European citizens (EC, 2014).

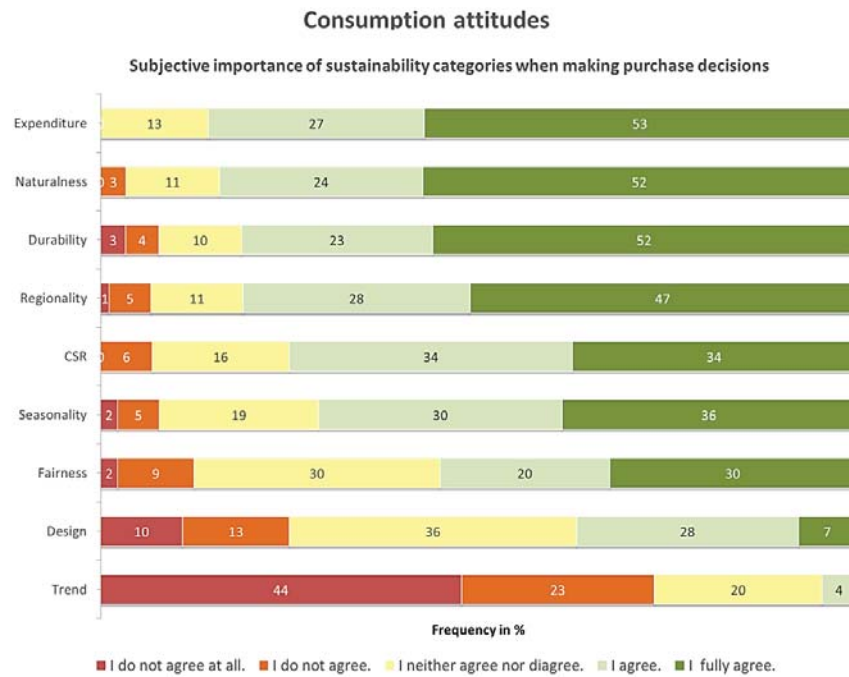


Figure 8: Level of agreement with consumption related statements.

Table 1: Consumption attitudes of the participants.

Statement	Sustainability Aspect	N	Max.	Min.	Av.	Std. Dev.	Median
I like to follow the latest trend.	Trend	90	4	1	1.83	0.93	2.0
I prefer regional products.	Regionality	91	5	1	4.24	0.95	5.0
I mainly decide depending on the design.	Design	93	5	1	3.10	1.08	3.0
A long lifetime of a product is very important for me.	Durability	92	5	1	4.26	1.04	5.0
I would spend more money on a sustainable product.	Expenditure	92	5	3	4.42	0.73	5.0
I prefer seasonal products.	Seasonality	92	5	1	3.99	1.01	4.0
I try to ensure that no humans or animals were exploited.	Fairness	91	5	1	3.73	1.09	4.0
I prefer low-emission, close-to-nature products.	Naturalness	89	5	2	4.38	0.83	5.0
It is important that companies act socially and ecologically responsible.	CSR	90	5	2	4.03	0.93	4.0

### Attitudes towards Industrial Hemp

The associations of the participants to IH were tested, the results are shown in Figure 9. Most frequently stated associations were “clothes/textiles” (81%), “renewable resources” (80%), followed by “ecological” and “rope/cordage” (77%, respectively) “insulation material” and “sustainable” (67 and 63%). Interestingly, only 12 of the 118 participants indicated negative associations (“drug” or illegal”). As no single study on the associations and attitudes of European citizens towards industrial hemp exists, no comparison to literature data can be performed.

When asked for their knowledge on the historical significance of IH (Figure 9), most participants knew about the usage as cordage (80%) and for textiles (78%), as well as the long-time cultivation (71%), the importance as bast fibre (68%) and the higher historical significance compared to IH’s significance today. Only 6% stated to know nothing about the historical significance of IH.



The most well-known ecological benefits of IH were “renewable resource” (70%), “sustainable” (65%) and “positive impact on soil” (53%).

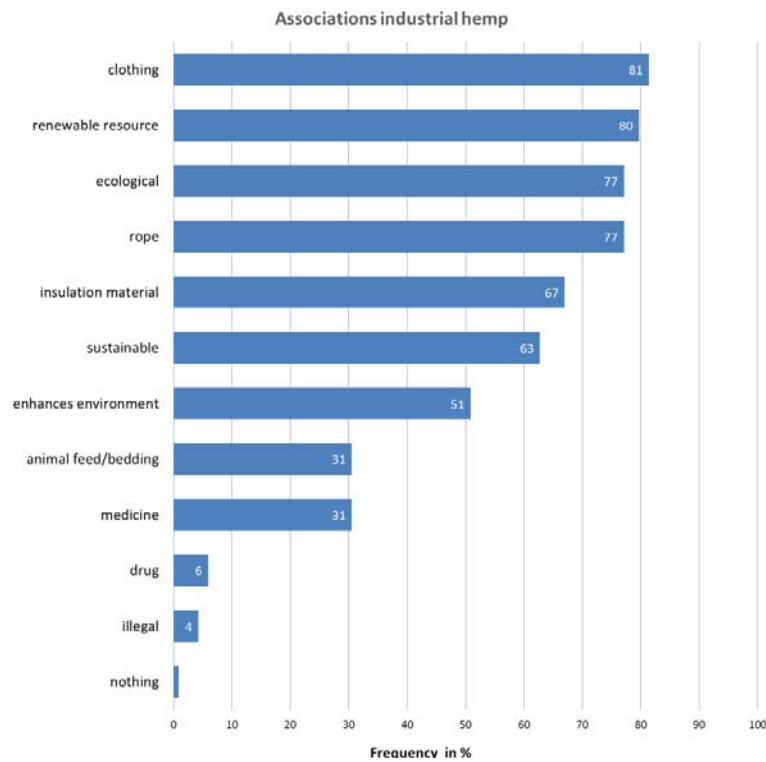


Figure 9: Associations to industrial hemp (N=118).

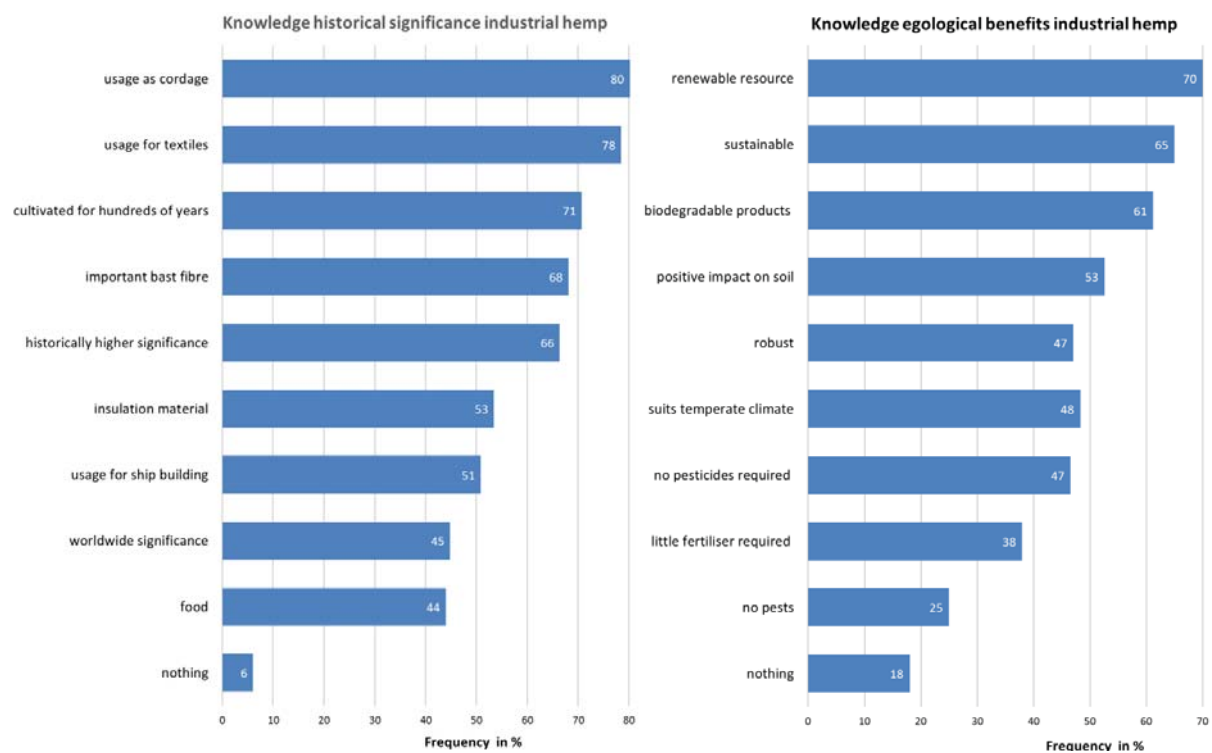


Figure 10: Knowledge on the historical significance and the ecological benefits of industrial hemp (N=118).

The hypothesis was formed that participants who know more about the ecological benefits or historical significance of IH (i.e. give many associations), also give a larger number of positive associations towards IH, i.e. have a positive attitude towards IH. Despite a relatively

high spread of the data (Figure 11), a significant correlation could be found between ecological benefits knowledge and positive associations ( $R^2$  value of 0.539) and an even stronger correlation between the knowledge on historical significance and positive IH associations ( $R^2$  value of 0.709). Even though the possibility exists that participants who give a multitude of answers to one questions are generally more likely to give many answers, this hypothesis can be regarded as true. This finding indicates that an education on the enormous significance IH once hold around the world (Mignoni, 1999) and the various ecological benefits associated to cultivating IH (Piotrowski and Carus, 2011) may have a positive effect on the attitudes towards IH, which would be in good accordance with the answers of all interviewees who indicated the great importance of education on the benefits of hemp to promote the wider use of hemp.

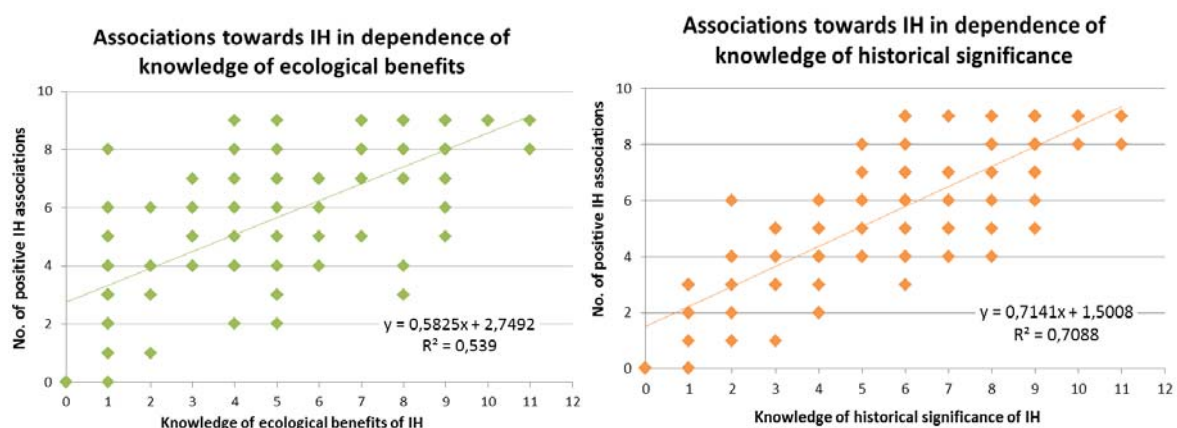


Figure 11: Correlation between the number of positive associations to industrial hemp and the extent of knowledge on the ecological benefits (left) and the historical significance of IH (right) as quantified by the number of given answers.

### Industrial Hemp Consumption Behaviour

Further, the relationships between the average potential hemp purchase, calculated as the mean value of the likeliness to purchase the different IH products in the future, and the specific SC attitude was calculated for every participant for each of the nine SC categories. The results are displayed in Table 2.

Table 2: Correlations between the potential hemp purchase and consumption attitudes.

Sustainability Aspect	Person Correlation	Spearman Correlation
Trend	-0.099	-0.055
Regionality	0.229	0.328
Design	0.156	0.160
Durability	0.074	0.162
Expenditure	0.372	0.491
Seasonality	0.260	0.365
Fairness	0.507	0.495
Naturalness	0.405	0.473
CSR	0.386	0.513

Person as well as Spearman correlation was tested to evaluate the significance between the potential hemp purchase and the SC attitudes. While Pearson correlation is mainly used to quantify the degree of the relationship between linear related variables, Spearman rank

correlation does not need any assumptions about the data distribution and only requires ordinal data (SS, 2016). For the data, Spearman correlation appeared to be more suitable. Significant correlations could be found for the aspects CSR ( $p=0.513$ ), fairness (0.495) and the willingness to spend more money on sustainable products (expenditure, 0.491) and the likeliness to purchase natural products (0.473). A weak correlation could be found between potential hemp purchase and tendency to buy regional (0.328) and seasonal (0.365) products. Both, Person and Spearman correlation resulted in similar results.

## Conclusion

The main objectives of this study were to analyse prevailing attitudes towards IH in Europe and to correlate these to sustainable consumption attitudes and sociodemographic data. The general attitudes of the participants towards industrial hemp were very positive. Associations to IH were mainly in the product areas of textiles, ropes and insulation materials, as well as in the property areas renewable resource, ecological and sustainable. Hardly any negative associations could be found.

A large knowledge gap regarding the historical significance and ecological benefits of hemp was revealed and a significant correlation between the knowledge in these areas and the amount of positive associations towards IH could be found.

A correlation between the SC attitudes and the likeliness to purchase IH products in the future could be found. Especially participants who put a strong emphasis on fair production conditions, corporate social responsibility and naturalness of products, as well as those who are willing to pay more for sustainable products are very likely to purchase IH products.

The results of this study show that attitudes and knowledge around industrial hemp is very limited - at least among the investigated group of citizens. A correlation between the attitude towards industrial hemp and the likeliness to purchase IH products could be identified.

As almost no prior work on people's attitudes towards industrial hemp exists, this work can only be regarded as a first step towards analysing this complex topic. Thus, various areas of future work can be determined. As the sample analysed in this study had a high educational background as well as strong environmental and sustainable consumption attitudes, future studies should also involve different groups with lower educational background and environmental attitudes.

A comparison of different European countries, which was hardly possible in this work due to the limited number of participants from respective countries, would be very interesting. Especially the comparison between citizen's opinions in countries with a long and continuous tradition of growing hemp, such as Romania or France, and other European countries is of great interest. Also, a comparison to non-European countries is needed to assess the potential of hemp companies around the world. An additional area of IH attitude's research is the analysis of the impact of legislation on people's opinions. Are the changing laws on hemp cultivation affecting people's attitudes towards IH products?

## References

Abbott, M. and McKinney, J. (2013) *Understanding and Applying Research Design*, Ebook Library. Available at: <http://reader.eblib.com/%28S%28ilx5dge3wi3e2gkigo15ny2h%29%29/Reader.aspx#> (Accessed: 24.01.2016).

Baker, A. (no date) *Effects of Public Opinion on the Marketing of Hemp Products via the Internet*, Baker College Center for Graduate Studies, US, Available at: <http://druglibrary.org/schaffer/hemp/indust/RESPAPER.html>.

- Bem DJ (1972) Self-Perception Theory. In L. Berkowitz (Ed.), *Advances in Experimental Social Psychology*, 6, New York: Academic Press, pp. 1–62.
- bpb (2014) *Bildungsstand der Bevölkerung*, Bundeszentrale für politische Bildung, website, Available at: <http://www.bpb.de/nachschlagen/zahlen-und-fakten/soziale-situation-in-deutschland/61656/bildungsstand>.
- Carus, M (2013) *Market data on Industrial Hemp – fibres, shivs and seeds*. Germany: European Hemp Association.
- CIA (2016) *The World Factbook*, website, Available at: <https://www.cia.gov/library/publications/the-world-factbook/fields/2177.html>.
- Crescini, F. (1971) *Piante Erbacee di Grande Coltura*, Rome : Reda, pp. 167-195.
- Crowe (2013) *Between the market and the state*, in Harrison (2013) *People over Capital - The co-operative alternative to capitalism*, Oxford: New Internationalist Ltd.
- Destatis (2016) *Bevölkerungsstand*, website. Available at: <https://www.destatis.de/DE/ZahlenFakten/GesellschaftStaat/Bevoelkerung/Bevoelkerungsstand/Bevoelkerungsstand.html;jsessionid=47DB45F376F767B3771D273F3843AB11.cae3>.
- EC (2011a) *Youth Attitudes on Drugs - Flash Eurobarometer #330*, The Gallup Organization, Available at: [http://ec.europa.eu/public\\_opinion/flash/fl\\_330\\_en.pdf](http://ec.europa.eu/public_opinion/flash/fl_330_en.pdf).
- EC (2014) Attitudes of European citizens towards the environment – Special Eurobarometer 416, Brussels: European Commission. Available at: [http://ec.europa.eu/public\\_opinion/archives/ebs/ebs\\_416\\_en.pdf](http://ec.europa.eu/public_opinion/archives/ebs/ebs_416_en.pdf).
- Henkel (2015) *Improving the life cycle sustainability of products with a sustainable consumption index*, website, Available at: <http://www.scp-centre.org/projects/basic-projects-data/82-henkel-sustainability-master-sustainable-consumption-index.html>.
- Hubpages (2015) *Why Pot is Illegal*, Available at: <http://hubpages.com/politics/Legalizing-Pot>.
- Karus, M (2005) *European Hemp Industry 2001 till 2004: Cultivation, raw materials, markets and trends*. Germany: European Hemp Association.
- Jones, J.F. (no date), The theory of attitude formation and change and its application to social group work.
- Katz, D. (1960) The Functional Approach to the Study of Attitudes. *Public Opinion Quarterly*, 24, pp. 163-204.
- Laws, S. and Harper, C. and Marcus, R. (2003) Communication with Respondents – the Key to Good Research. In: *Research for Development*, London, England: SAGE Publications, pp. 248-259.
- Lenton, S. and Frank, V. and Dahl, H. and Potter, G. (2015) Attitudes of cannabis growers to regulation of cannabis cultivation under a non-prohibition cannabis model. *International Journal of Drug Policy*, 26(3), pp. 257–266.
- McCombs, M.E. and Shaw, D.L. (1972) The Agenda-Setting function of Mass Media, *The Public Opinion Quarterly*, 36(2), pp. 167-187.
- Michka (1994) *Building with hemp: A report from France*, Paris, France. Available at: <http://www.hempfood.com/IHA/iha01209.html>.
- Mignoni, G. (1998) *Cannabis as a licit crop: recent developments in Europe*, UNODC, Available at: [https://www.unodc.org/unodc/en/data-and-analysis/bulletin/bulletin\\_1997-01-01\\_1\\_page003.html](https://www.unodc.org/unodc/en/data-and-analysis/bulletin/bulletin_1997-01-01_1_page003.html).
- Moschis, G.P. and Churchill, G. A (1978) Consumer Socialization: A Theoretical and Empirical Analysis *Journal of Marketing Research*, 15( 4), pp. 599-609.
- NG (2014) Greendex 2014: Consumer Choice and the Environment – A Worldwide Tracking Survey, Available at: [http://images.nationalgeographic.com/wpf/media-content/file/2014\\_Global\\_Report-cb1411689801.pdf](http://images.nationalgeographic.com/wpf/media-content/file/2014_Global_Report-cb1411689801.pdf).
- Piotrowski, S. and Carus, M. (2011) Ecological benefits of hemp and flax cultivation and products, NOVA Institute. Available at: <http://eiha.org/media/2014/10/Ecological-benefits-of-hemp-and-flax-cultivation-and-products-2011.pdf>.
- Ritter A. and Borchardt, M. and Vaccaro, G. and Pereira, G. and Almeida, F. (2015) Motivations for promoting the consumption of green products in an emerging country: exploring attitudes of Brazilian consumers, *Journal of Cleaner Production*, 106, pp. 507-520.
- SS (2016) *Correlation (Pearson, Kendall, Spearman)*, website, Available at: <http://www.statisticssolutions.com/correlation-pearson-kendall-spearman/> (Accessed: 26.01.2016).
- Statistika (2016) *Einkommen (Nettoverdienst), d.h. Lohn oder Gehalt nach Abzug von Steuern und Sozialversicherungsbeiträgen, im letzten Monat*, website, Available at: <http://de.statista.com/statistik/daten/studie/179897/umfrage/hoehe-des-nettoverdienstes-im-letzten-monat>.
- Thomas, S. (2004) *Putting the Questionnaire Together. Using Web and Paper Questionnaires for Data-Based Decision Making*, pp. 67-83, Thousand Oaks, CA: SAGE Publications, Inc. Available at: <http://dx.doi.org/10.4135/9781412986496.n4>.

## Riverside Market Project, San Isidro de Heredia, Costa Rica

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**Abstract:** During 2011 a client came seeking assistance for the development of a roadside property located on the main highway to the Caribbean Coast from Costa Rica's capital San José; he had in mind a barbecue restaurant for truckers and road users, but was challenged to ponder on pursuing a truly sustainable and inclusive approach for his project. A living and evolving micro-urban system inspired in *permaculture* was proposed. After the initial conversations, the owner went on to study sustainable production practices, bio-intensive agriculture, wood construction and related topics. He came back on 2013 and the first phase was finally built in 2015. It all was to start as a small roadside café, with the eventual establishment of an organic marketplace. Significant portions of old walls and floors remaining on site, as fragments of a formerly burned down building, were salvaged/recycled and utilized in combination with new light wood structures, minimally touching the ground yet maximizing space quality and use. The small cafe quickly turned into a lively and successful brick-oven pizza place and gastro-pub with current plans to expand into the diversified organic marketplace once imagined. Key sustainable building features include the salvaging of existing structures and floors, the use of reforestation wood (teak, melina) processed on site, and the implementation of passive tropical design strategies. The project has its own organic orchard and composting systems and priority is given to locally sourced produce and products. Electrical energy expenditure is minimized by traditional wood cooking methods. The venue has positively influenced and contributed to the local community and the sustainable/organic culture of our small green country. It all combines together to create a business model based on sustenance, learning and information exchange, adding up to much more than the sum of its parts.

**Keywords:** Low carbon, adaptive, passive tropical

### Introduction

Over the course of the year 2011, the authors of this paper, Daniel Harris, owner, and Julio Jiménez as Architect/Engineer, met in order to start design work on a project located in San Isidro de Heredia, Costa Rica. Since September 2009, Julio had been pursuing postgraduate studies in sustainability at the Center for Alternative Technologies (CAT), focusing mainly on passive tropical design for non-developed regions, adaptive principles, permaculture and holistic approaches, all in order to come up with proposals for an architecture of the present time in our home country, Costa Rica.

Conversations started on the original idea of building a roadside restaurant, but the scope and vision of the project quickly turned into the dream of an evolving and sustainable micro-urban market conceptually based more on permaculture principles adapted to our local realities, than on the more prevalent eco-efficient practices (Gunderson et al, 2009, Holmgren, D., 2002, Homer Dixon, T., 2006). Taking it at heart, Dan went on to prepare himself for the challenge, studying on his own the principles of sustainable development, bio-intensive agriculture, sustainable wood processing and construction, among other related topics of interest to the project. The design process finally started after more than a year of further preparation.

From the onset, the austere and simple building newly raised was like a magnet for sensitive persons looking for alternative places for leisure and enjoyment. Further on, it has attracted people from all standards, classes, trades, cultures and ages, unfolding since its beginning as an inclusive venture for all (Figure 1). Being completely self-financed, the



business is now ready to expand, incorporating new market elements that will take it one step further into the lively micro-urban system once envisioned.



Figure 1. Riverside Market first phase: roadside café/restaurant

We are convinced that what has made Riverside Market a successful venture both from a business and sustainable design standpoint has been the focusing on the root of a vision carried out honestly and attentively respecting the simple but key principles upon which it rests (Illich, I. 1973, Nicolescu, 2008, Odum and Odum, 2001).

### **Implemented Vision**

The vision established from the beginning was that of a lively, permanent food and retail space for commerce of sustainable products, focusing on artesian, healthy, local products both for taking out and in-place consumption. The place would act as a showcase for both traditional and innovative food preparation approaches, arts and crafts as well as live music. The finishing of the spaces would be simple, un-pretentious, yet comfortable, for people to enjoy their time while chatting, shopping, eating and relaxing with friends and family in an informal, market-style environment (Figure 2). The whole design and construction process was to be performed bearing in mind the patient and constant unfolding of events on a step-by-step basis.

A very important feature of the vision for the place included the establishment of an open and free setting for the exchange of information regarding the production, the practices, the care, all producing an experience for the people, as important as the inherent commerce of goods.



Figure 2. Riverside Market, main vestibule

The feedback generated by this information exchange dynamics, back into the project, contributed to create a living organization requiring continuous evaluation, analysis and modifications/improvements over time. As a result, the vision of the project transpires within the physical setting of the place and its values are transmitted through experience, rather than explicitly expressed in written or verbal terms, therefore generating interest out of the emotional response of the users to the lived experience within the space.

Moreover, the vision pursued is being continuously enriched, matured and transformed over time, incorporating new input from friends, business partners, clients and the community.

### **Making the Best out of the Existing**

The Property is a 4750 meter lot located 20 minutes outside of San Jose (capital of Costa Rica) on the highway to the Caribbean coast and Atlantic port on the outward-bound traffic side of the highway. It has approximately 50 meters of frontage on the main highway to the Caribbean. A stream runs along one of the sides and the back of the lot. The edge of the stream is wooded and the vegetation provides shade and a nice setting for outdoor seating, gardening, and other outdoor activities (Figure 3).

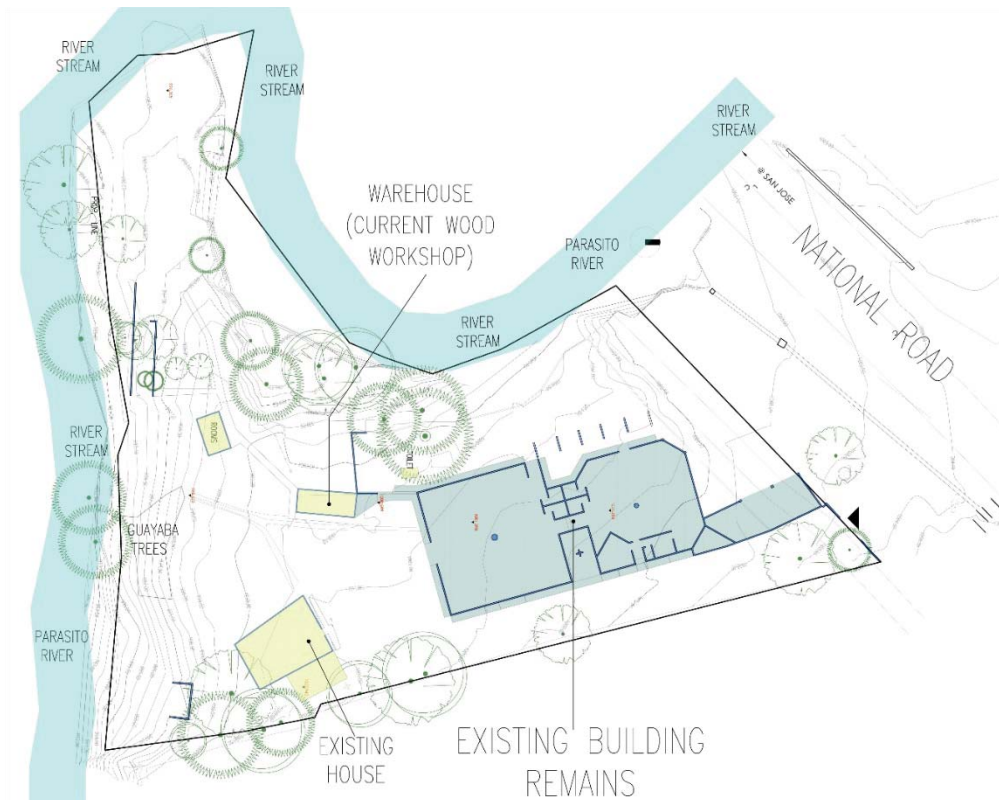


Figure 3. Plan of existing physical conditions

The site was home to a Bar-Restaurant-Disco complex built back sometime in the 80's and burned down in the 90's. Before the project was built, the floors and burned out shell of these structures was all that remained on the site (Figure 4). Under these conditions, it was decided that the construction footprint would not be enlarged with respect to the old, existing remains. Further on, it was determined that the construction project would salvage as much as possible of the original structures and floors remaining in place. It was like building on top of the ruins of the "old paradigm" (Figure 5).

Structural rehabilitation was implemented on an as-needed basis in order to save and make use of the existing wall structures.

In addition to that, an existing A-frame house on the back side of the property was refurbished and made available for the budget eco-crowd. Since the startup, renters have been offered the opportunity to pay low price or even for the exchange of their work in the vegetable gardens. Meanwhile plans to improve the house over time are in place, increasing its rental capacity, while opening up the different living areas for greater ventilation, circulation and improved views. Future plans for it include a wrap-around porch, balconies, and dormers in order to improve building space use.



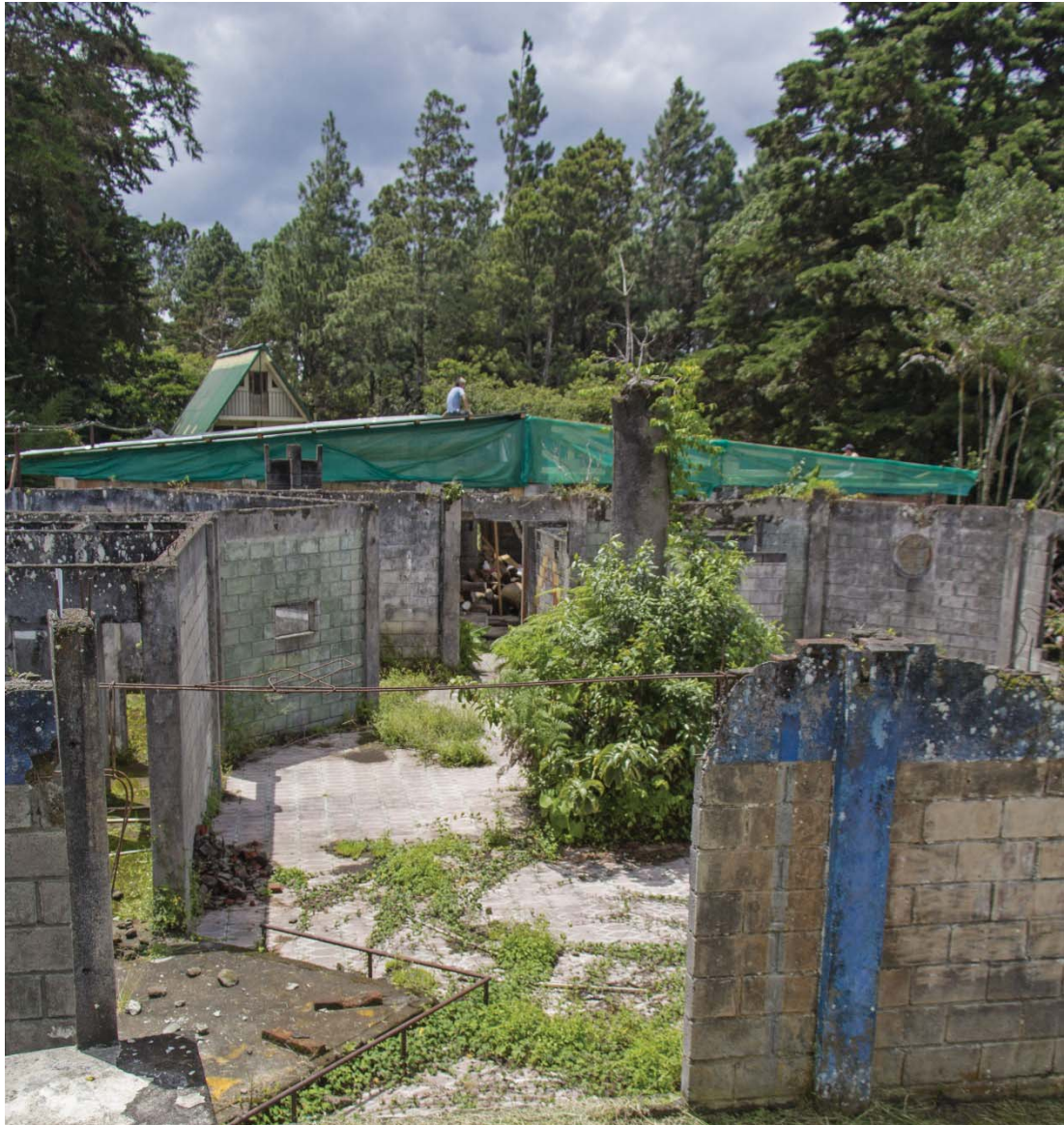


Figure 4. Existing construction remains



Figure 5. Structural rehabilitation of existing damaged walls



Finally, the back side of the existing main structure was taken over to install the wood processing shop to be used initially for construction purposes, but later for sustainable furniture production and on-site sales.

### **On-site Wood w/o Orthodoxy**

Since Dan had reforestation wood available (cypress, teak and melina), both from prior purchases and barter, but also from other nearby properties, it was given that the reconstructed structure in its new, improved form, was to be constructed in wood. Bearing that in mind, the original design was produced using the shapes and lengths that the on-site shop was able to produce. The result of this design proposal is shown in Figure 6.



Figure 6. Architectural/Structural all-wood proposal

Nonetheless, just as construction started, it was clear that even while having an on-site wood processing shop, doing it all in wood would be a more expensive, difficult and slower process than having the benefit of freely introducing some light gauge steel elements which would significantly simplify the job. The simpler and actually cleaner result in terms of spaciousness and structural clarity is shown in Figure 7 and Figure 8. Roof height was planned bearing in mind vertical growth on second floor mezzanines, in order not to enlarge the existing building footprint over the course of future expansions.



Figure 7. Final structural resolution incorporating light gauge steel elements





Figure 8. Finished roadside café/restaurant

### Passive, Local, Simple

The simple building volume and tectonics were resolved both bearing in mind the respect of local vernacular practices and passive tropical principles. Form and tectonics followed the indications of weather and constraints, rather than a deciding upon a pre-determined style dictated from outside. In fact, some details were left to be resolved over time, knowing that *nature knows better* (Figures 9 and 10).



Figure 9. Semi exposed and planted circulation pergola





Figure 10. Well shaded, ventilated space showing height and inside/outside alternations

Among the main tropical passive features taken into consideration in the building design, we can cite the following (Liebard et al., 200, Sacré et al, 1992):

- Use of tall, well ventilated roof structures with airy, indoor-outdoor feel, bearing in mind the alternation of hot/cool weather and rainy climate.
- Large overhangs and pergolas to deal with alternate sunny/rainy weather.
- Ceiling height alternations.
- Threading of inside/outside spaces, honoring and actualizing old-established vernacular practices.



Figure 11. Open, flexible space showing salvaged walls, wood structure, brick oven, on-site fabricated furniture

As a result, the space created yields an *open market* feel with different informal seating options and potential spaces for future specialized kiosks and food stands. Further

on, given its characteristics, the site offers outdoor seating options by the stream, under the trees among many other unpretentious, enjoyable interaction spaces that can be created over time (Figure 11).

### Low Carbon Food

The other key feature that inevitably both attracts and informs visitors on sustainable practice through lived experience is the low carbon food being produced in place. Of course this concept and practice is extrapolated to the rest of business options currently swarming around the place. Firstly, cooking has a very low energy consumption rate since most of the food served is cooked/baked in the brick oven built for this purpose (Figure 14). Secondly, all of the organic food leftovers go to the on-site composting area that produces organic fertilizer for the on site orchards.

In combination with the locally sourced organic produce and products utilized as part of the cooking and retail activities, this practice contributes to create a truly sustainable project not only from its construction, but also from its operation and its complete life cycle standpoints. Thereby, the project sets an example on sustenance and adaptability to changing times and circumstances that demand the creation of low carbon cultural options within a contemporary framework begging for optimism (Figure 12).



Figure 12. Wood oven pizza with site-produced organic produce and artisan cold tea

### Sustainable Building Model

The other keystone of this discrete, yet successful project is the sustainable building model it is set upon, first and foremost based upon the honoring of our local heritage, our traditional and locally produced foods and customs, yet incorporating some of the good and enjoyable influences that we inevitably receive from abroad in an era of cultural globalization. As said before, the business top priority is to buy from and use locally sourced

produce (buy direct from farmers in the area), as well as use and promote innovative, locally produced goods and products.

In economic terms, the project has been self-financed, with some “bootstrapping” by the owner. This has demanded the ability to make small steps with small levels of investment over time in order to be able to achieve the project objectives.

The organization targets businesses with products and values that are compatible with the nature and values of the project. When warranted, the owner has been open to entertain different forms of alliances, partnerships, leases, build-to-suit agreements, and other configurations that will ultimately help attract and retain the ventures and people that are aligned and contribute/enrich/support the project values.

Ultimately, the goal of the owner is to create a self-sustaining conglomerate of micro-organizations, run by independent business managers, each with ownership, true expertise and passion for their business category (examples: Baker, Coffee Roaster, Chocolatier, Organic Produce Trader, etc). These businesses will ultimately either pay rent or share in their profits in order to provide ongoing cash-flow to the development. The owner is currently involved at the operational level in the overall marketplace and may choose to remain involved in some of the other upcoming business categories.

From its principles, the organization strives to make positive contribution to the local community, not only providing a space for healthy food, entertainment and information exchange, but also sourcing as much as possible from local farmers and businesses, thereby offering diverse opportunities for working and learning, careers and education, as well as opportunities for the development of local musicians, artists, self-motivated youngsters. Riverside Market currently promotes and performs training workshops on sustainable bio-agriculture, and participates in river cleanup/reforestation activities among other synergies, all within a *triple bottom line* approach.

## Outlook

From the outset, it was decided that the project would start with a reduced number of small-scale initiatives in line with the overall project vision. Over time the project would evolve to fulfill its ultimate goals and vision through an adaptive and organic growth process that would allow to incorporate the learnings along the path back into the design/construction/operation. Thereby, the resulting living project would be an adaptive system under demand-driven growth.

From the initially small roadside café once envisioned, which would act as a small-scale example and concept for rest of the project, in combination with a small backpackers lodge on the back, the owner is currently in conversations to introduce a permanent organic produce market, a second brick oven bakery space, a space dedicated to coffee roasting and gourmet organic coffees, another space for the production and sales of Costa Rican organic chocolate, among other that are part of the updated master growth plan developed by the authors (Figure 13).





Figure 13. Current Riverside Market master growth plan

## Conclusion

Riverside Market in San Isidro de Heredia, Costa Rica is a small but meaningful and locally successful project in terms of sustainable building practice, business model and operations, social and cultural influence, as well as a contemporary business organization based on principles of sustenance and adaptability. The key of the positive results obtained is the dedicated implementation of the vision and values established up front, while making the best out of the existing physical possibilities at hand, employing technically proven practices without falling upon orthodoxy, working at the service of a truly low carbon approach and establishing a sound and sustainable business model. Improvements are possible and desirable, especially regarding more technical rigor, data gathering and processing/monitoring.



Figure 14. Core of the brick oven



## References

- Gunderson, L., Allen, C. and Holling C., eds (2009). *Foundations of Ecological Resilience*, Washington DC: Island Press.
- Holmgren, D. (2002). *Permaculture – principles and pathways beyond sustainability*, Victoria, Australia: Holmgren Design Services.
- Homer Dixon, Thomas, (2006). *The Upside of down – Catastrophe, creativity and the renewal of civilization.*, Washington DC: Island Press.
- Illich, Ivan (1973). “La Convivialité”, Paris : Editions du Seuil.
- Liébard, A. and De Herde, A. (2000). *Guide de l’architecture bioclimatique – Tome 2 : Construire avec le climat*, Paris, France : Observatoire des énergies renouvelables.
- Nicolescu, Ed. (2008) *Transdisciplinarity – Theory and Practice*, NJ, USA: , Hampton Press Inc.
- Odum, H.T. and Odum, E., (2001), *A prosperous way down – Principles and policies*, Boulder: University Press of Colorado.
- Sacré, C., Millet, J.R., Gandemer, J and Barnaud, G. (1992), *Guide sur la climatisation naturelle de l’habitat en climat tropical humide. Tome 1 : Méthodologie de prise en compte des paramètres climatiques dans l’habitat et conseils pratiques*, Nantes, France : Centre Scientifique et Technique du Bâtiment.

# Sustainable Heritage Preservation (Local and International Experiences)

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**Abstract:** This paper is an attempt to shed light on the role of sustainability in the policies of heritage preservation. It aims to get benefit from the various methods to preserve the architectural heritage which has been studied in international experiences in order to reach a methodology to utilize the principles and techniques of sustainability in heritage preservation. The study identifies heritage preservation in terms of sustainability policies and clarifies the reasons behind its importance. There are multiple factors that threaten architectural heritage buildings of being damaged. Therefore, an urgent interference to reduce the effects of that damage is highly required. Thus, it is important to raise the awareness of heritage preservation to sustainability, through developing an understanding of the characteristics of heritage buildings and identifying the main points needed for optimizing the performance of heritage buildings. Furthermore, this paper intends to examine the extent to which the principles of sustainability are applied in the preservation of heritage buildings in Egypt. In addition, it outlines the reasons why traditional buildings are considered to be examples of sustainability and the way to develop them to be more sustainable without damaging their character. Finally, it illustrates the ways of utilizing tried building techniques and the materials to meet recent standards for sustainability and energy conservation.

**Keywords:** Sustainable Heritage Preservation, Sustainable Site, Water & Energy Efficiency, Material Selection, Indoor Environmental Quality.

## Introduction:

Heritage shows the concept of transmission from the past to the future. It must be considered as a value received from the ancient ages and has to pass to the upcoming generations. It is also reports about the traditions, practices, persuasions and the achievements of a nation and its people. The goal is to provide an idea based on theories and philosophies of sustainable preservation and heritage management, thorough underlying their importance and ethics. This paper aims to focus on the policy and the procedures applied in sustainable preservation of heritage buildings. It also studies the preservation of existing heritage building within sustainable principals . Heritage preservation is related to the social, economic, and environment sustainable development. *(Figure 1 below shows some of heritage preservation's values: cultural, aesthetic, educational, environmental, social, historical, and economic.)*

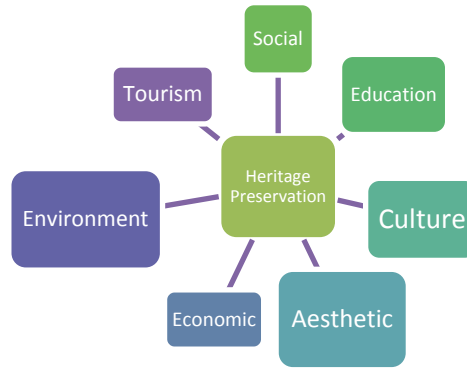


Figure 1. Heritage Preservation's Values (by author)

### Methodology:

Studies and researches in the field of heritage preservation, conservation, restoration and the adaptive reuse are all taken into consideration. In addition, preservation has been widely studied in the various matters of urban restoration, engineering, environment, sustainability, society and economy (Bullen P., 2010). Considering the recent academic studies of the environmental relationships with heritage buildings, sustainability was disciplinary the main concern of these studies. It is obvious that there has been an expansion in problem-oriented joining the preservation process and sustainability principles in the emerging field of environmental studies representing the development and the common ground between these approaches. The preservation environmental problems can be placed at different points between disciplines and development. (Figure 2 below shows the methodology of the sustainable heritage preservation research)



Figure 2. Methodology of the process of preservation in line with sustainable development of the case study (by author)

For example, architectural heritage preservation could happen at the connection between ecology and various social sciences (economics, social sciences, and political studies) which make sustainable preservation one of the most important solutions for the future earth protection.

### Sustainability:

As mentioned in the United Nations Brundtland Commission's 1987 report, generally sustainability is defined as **"development that meets the needs of the present without compromising the ability of future generations to meet their own needs."** (U.N.G.A, 2010).

Sustainability forms and sustainability definitions recently became popular to our daily vocabulary. Buildings & constructions are negatively impacting us and influencing our

environment through the Irresponsible use of row materials like minerals, wood, water and energy resources. (Figure 3 below shows the three main dimensions of sustainability)

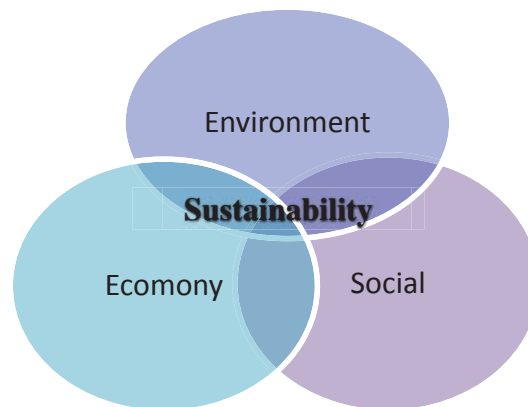


Figure 3. The three dimensions of sustainability (Journal of Dairy Science, Jul 2013)

### Heritage Preservation:

Heritage Building Preservation can be defined as: the performance of preserving property, returning them to their original position or an improved situation. And according to preservation specialists it is: “All actions taken to maintain an object in its existing condition, minimize the rate of change, and slow down further deterioration and/or prevent damage are part of preservation.” (Burra Charte, 2010)

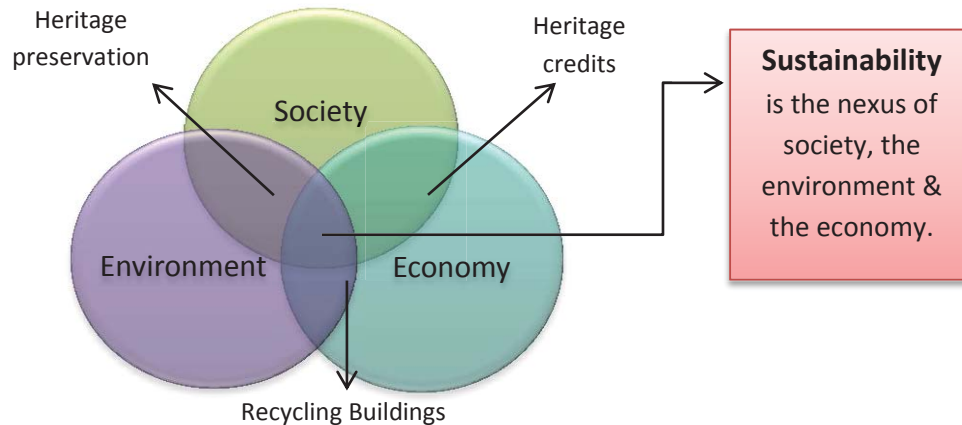
### Preservation & Sustainability Development:

Sustainable development is defined as “the means to providing the basic necessities of life... to meet our needs today while enabling future generations to meet their needs” (Routledge, 2004.) The preservation process involves: Reporting the treatment of any case and documenting the decisions and the procedures , Preserving the integrity and authenticity of the objects, Innovating an unharmed environment, which involve controlling heat, cold, humidity, light, noise and other pollutants ,Controlling the conditions of its use, including display and visitor interaction, Physically treating and monitoring objects in order to, as nearly as possible, maintain the object in an unchanging state and to stabilize its condition. (Figure 4 below shows the heritage preservation process)



Figure 4 . Heritage preservation process (by author)

Heritage preservation and sustainability are natural partners. Heritage preservation reduces material consumption and waste resources. It also saves more energy than destroying properties and building new ones. However, the preservation of heritage buildings has not always been the aim of the sustainable action. Energy efficiency in heritage buildings can be upgraded using new technology to maximize energy performance. In addition, historic features can be repaired and restored for a higher efficiency. (Merlino Kathryn.,2011) (Figure 5. below shows that the sustainability is the connection between society, economy & environment)



**Figure 5. Preservation of heritage buildings is inherently a sustainable practice (by author)**

### International Experiences:

All over the world, there are some examples that have achieved sustainability in many different aspects; starting from the strong performance of the sustainable sites which includes water efficiency, energy efficiency, material and resources, down to the indoor environment quality and innovation.

#### 1. Balfour Guthrie Building, Portland, Oregon, USA

##### 1.1 Building information: (WBDG Historic Preservation Subcommittee, 2017)

- Location: 733 SW Oak Street Portland, Oregon, USA.
- Building Type: Commercial Office.
- Construction Type: Historic preservation.
- Area: 557.4 m<sup>2</sup>.
- Project Scope: 2 stories building.
- Original Architect: Morris Whitehouse.
- Date of Construction: 1913.
- Architectural Style: American Renaissance
- Architect: Thomas Hacker Architects, Inc. (THA)
- Date of Renovation: 2002 (Preservation + Adaptive Re-use)
- Owner and Developer: Thomas Hacker Architects, Inc. & Gray Purcell, Inc.
- Project Cost: \$3 million.



- Completion Date: May 2002.
- Ratings Certification & Awards: LEED Silver.  
(Figure 6 below shows the Balfour Guthrie Building in past & in present)

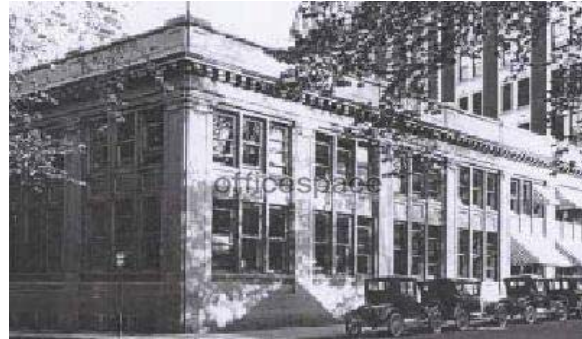


Figure 6. The Balfour Guthrie Building (Present & Past)

Photo credit: <https://www.wbdg.org/design-objectives/historic-preservation/sustainable-historic-preservation>

## 1.2 Sustainable Features:

### 1.2.1 Sustainable Site Development:

The original location was planned to be a "park blocks" which is a natural open space that goes along the length of the downtown. (O'Connell, Kim A, 2003). However, being at the intersections of the Pearl District, China Town, and Downtown, makes it accessible from all the public transportation, innovative landscape design & land development and management turned it to a sustainable site. (Campagna Barbara, 2008). (Figure 7. shows the site of the Balfour Guthrie)



Figure 7. The Balfour Guthrie Site  
Photo Credit: Google Earth

### 1.2.2 Water Efficiency:

For a best water and energy consumption, they composite an energy -Star Rated System- in the kitchen to use point source water heaters at all taps which is better than the standard tank style heaters that lose heat as the water inside cools down. It has also achieved water consumption with the low-flow fixtures and toilets. (Campagna Barbara, 2008)

### 1.2.3 Energy Efficiency :

The flexibility of the building is demonstrated through the decentralized HVAC system. Sensitive to the building's inherent design aspects, such as the western facade's large windows, the system consists of automatically dimming lights that allow for "daylight harvesting" activated when direct sun is available and overhead light is not needed. Jonah Cohen, one of four principals at THA, reports that while the energy modelling projected a 24% better than code energy performance, in actuality, they are experiencing energy usage that is 40% better than code. (Johnson Bethany, 2009) (Figure 8. below shows some features of the interior of the Balfour Guthrie building)



Figure 8. The interior of Balfour Guthrie shows the double hung windows & the Interior storm windows help to maintain the historic look while increasing energy efficiency.

Photo credit: <http://www.residentialarchitect.com/practice/workspace-tha-architects>

### 1.2.4 Materials Selection:

A cross-section of the historic concrete is exposed, revealing materials in this early construction method. The removal of part of the first floor plate further allows the basement to take advantage of sunlight which is a desirable feature acknowledged by LEED. The stripping of many layers of gray paint from the exterior of the building exposed the original sandstone veneer facades. THA desired to protect the sandstone exterior by applying a protective coating. They sought the approval of SHPO (*The state historic preservation office*), who required inspection and ensured the application did not alter the colour or appearance of the historic material. (Campagna Barbara, 2008)

The SHPO closely monitored the proposed design as the owners restored the remaining historic fabric within the entry lobby. Three different species of wood grace the lobby, acknowledging the historic material and design through a sustainable approach (Solomon Nancy, 2003). Dark stained, tight grained, old growth white oak from the original design and construction remains as panelling in the stairway leading up to the first floor. In homage, but not replication, the entry doors to THA's office are new, responsibly harvested, white oak left unstained as a distinction between contemporary and historic fabric. The third species of wood in the lobby is found in the old growth Douglas fir entrance doors. Recycled wood from Portland's dismantled dry-dock; the wood is also left unstained in order to expose the tight grain of the old growth wood, conveying its own story.

### 1.2.5 Indoor Environmental Quality:

The wall of windows and the floor opening allow visual access to the outside where trees and sky can be seen from the basement as well. The building's program was designed to increase office interaction between the floors by locating the kitchen and main bathrooms in the basement. The variation in work setting allows accommodation for those who enjoy either the basement or first floor setting by frequently moving teams and desks around the office. (Johnson Bethany, 2009)

## 2. Sede Centrale Ca Foscari (Ca' Foscari University of Venice) Venice, Italy

### 2.1 Building information: (Richard .M, 2013)

- Location: Dorsoduro, Venice, Italy.

- Building Type: Public university
  - Construction Type: Historic preservation
  - Area: 11052.4 m<sup>2</sup>
  - Project Scope: 3 floors building
  - Original Architect : Bartolomeo Bon
  - Date of Construction: 1453
  - Architectural Style: Gothic Architecture
  - Architect: Carlo Scarpa, Valeriano Pastor
  - Date of Renovation: 2004 restoration
  - Owner/Developer : The Italian Government
  - Completion Date: 2006
  - Ratings Certification & Awards: LEED Platinum
- (Figure 9. below shows the Ca' Foscari Building in past & in present)



Figure 9 . The Ca' Foscari Palace (Present & Past) (Photo Credit : [https://en.wikipedia.org/wiki/Ca%27\\_Foscari](https://en.wikipedia.org/wiki/Ca%27_Foscari))

## 2.2 Sustainable Features:

### 2.2.1 Sustainable Site Development:

The Ca' Foscari University Sustainable Site is characterized with its alternative commuting transportation by reduction of pollution and land development effects from automobile use for commuting by using alternative transportation such as: mass transit, bicycling ,walking, rideshare options like carpools; vanpools. These alternatives are low-emitting and also fuel-efficient. (Richard .M, 2013) (Figure 10. shows the site of the Ca' Foscari University)



Figure 10. Ca' Foscari University Site  
Photo Credit: Google Earth

### 2.2.2 Water Efficiency:

In water efficiency category, the project achieves a minimum indoor plumbing fixture & efficiency by reducing indoor fixture and fitting water use within buildings to reduce the burdens on the fresh water supply and grey water systems. Also, indoor plumbing fixture is achieved by maximizing indoor plumbing and fitting efficiency to reduce the use of the fresh water and consequent burden on local water supply and grey water systems. In addition, there were strategies and systems that produce a reduction in the indoor plumbing .The reduction percentage is 25%. (Richard .M, 2013)



### 2.2.3 Energy Efficiency:

The operating strategy provides a ground for practicing and system analysis. In addition to minimizing the performance of the energy, the building achieved sustainable purchases of 40% of total purchases of electric-powered equipment during the performance period such as some equipment (scanners, monitors, printers, computers, fax machines and copiers). (Rick, 2013). The university expanded an outstanding commissioning plan for the energy using systems, recorded the energy breakdown use in the building, registered the problems that affect occupants' comfort and energy use, and evolved potential operational changes to solve these issues. Finally, it identified improvements that will provide cost-effective energy savings and document the cost-benefit analysis (Richard .M, 2013).

### 2.2.4 Materials Selection:

Scarpa removed the student tribune and designed the boiserie panelling, using part of the same wood employed for the student gallery. (Figure 11. Below shows the boiserie which is both a connection and a separation between the room and the corridor). Its gliding frames which covered by cloth are used to hide the room. However, when they're closed they remind the give of the gothic window. The image of the gothic window is mirrored on the glass of the boiserie, with notable light effects. The project reduces the environmental harm from materials purchased, used, and disposed of in the operations within buildings in addition to having a management for the solid waste of the building and the site, classifying the requirements of the management credits and recycling of all harmful materials (Richard .M , 2013).



Figure 11. some interior pictures of the university showing the paneling system & the decorated ceiling in the palace  
(Photo Credit : [https://en.wikipedia.org/wiki/Ca%27\\_Foscari](https://en.wikipedia.org/wiki/Ca%27_Foscari))

### 2.2.5 Indoor Environmental Quality:

Ca' Foscari achieved sustainable in the indoor environment, by providing building operations, maintenance and upgrade teams with the opportunity to earn points for additional environmental benefits achieved beyond those already addressed by the LEED for Existing Buildings: Operations & Maintenance Rating System. (Giovanni P-2012).

### 3. Local Experience : Villa Zogheb, Alexandria, Egypt:

After the previous study of the international experiences of the sustainable preservation projects ,this is a discussion for applying the international sustainability principles on a local case study preservation project .

### 3.1 Building information: *(The Arab Contractors official documents -Osman Ahmed Osman & Co.)*

- Location: Alexandria, Egypt
  - Building Type: Administrative Building
  - Construction Type: Heritage preservation
  - Area:1000 m<sup>2</sup>
  - Project Scope: House with two floors
  - Original Architect : Victor R Ligar
  - Date of Construction: 1918-1939
  - Architectural Style: French Renaissance
  - Architect: The Arab Contractors *(Osman Ahmed Osman & Co.)*
  - Date of Renovation: 2013-2018 Preservation
  - Owner : Misr Insurance Company in Alexandria
  - Developer (Tenant) : Accountability State Authority (Egyptian Government)
  - Project Cost: 21 Million Egyptian Pounds
  - Completion Date: December. 2018 (not finished yet)
- (Figure 12. below shows Villa Zogheb in past & present)*



Figure 12. Villa Zogheb (Present & Past) .Photo credit : The Arab Contractors official documents *(Osman Ahmed Osman & Co.)*

### 3.2 Applying Sustainable Principles on Villa Zogheb:

#### 3.2.1 Sustainable Site Development:

The project's sustainable goals have been set according to the design principles such as reducing heat compact surface by specifying a green area that connects the landscape (non-structural spaces) to the building. *(Figure 13. Below shows the site of Villa Zogheb )*

In order to reduce pollution and land development effects from automobile use for transportation, Villa Zogheb located in heavily urbanized area near to many public transportation. It also can achieve site management policy by create and implement a site management policy that employs best management practices to reduce harmful chemical use, energy waste, water waste, air pollution and solid waste. By

using of low emissions maintenance equipment; of building exterior, pavement, and other impervious surfaces and by having in place native or adapted vegetation on 20% of the total site area.



Figure 13. Villa Zogheb Site.  
Photo credit: Google Earth



### **3.2.2 Water Efficiency:**

Villa Zogheb can achieve reduction of indoor water by calculate fixture and fitting performance to compare the water use of the installed fixtures and fittings with the use of right plumbing system, inspect all existing fittings or fixtures to ensure they are operating properly and make any repairs needed to bring all fixtures into good working order or permanently turn off water supply to nonfunctional units. The villa also can build water level metering by tracking water consumption and permanently installed water meters that measure the total potable water use for the building.

Also surrounding the villa by native or adaptive plants it can use less water, require less maintenance, require less fertilizers and resist pest better. Furthermore, water can be conserved by choosing the right landscaping features. Indoor water use Reductions can be achieved by using grey water as wastewater generated from wash hand and baths, which can be recycled on-site for uses such as WC flushing and landscape irrigation. Also insert Dual-flush toilets with two flush options which can reduce water use by 67% . To get the most benefits of the grey water and to prevent the risk of fire, it might be necessary to think about having a fire fighting external tank which can prevent all possible risks.

### **3.2.3 Energy efficiency:**

The electrical power supply is another area that this old building was not designed for at the outset. Villa Zogheb does not have its own electrical transformer and emergency power supply system. The routings of electrical power cables and trunkings, the locations of distribution boards and the backbone for information technology were not planned and integrated efficiently. However, it is understood that adding new electrical plantrooms and arranging electrical distribution are difficult jobs when architectural integrity and preservation is to be maintained.

### **3.2.4 Materials Selection:**

The buildings original high windows with its single-glazing can meet the sustainability standards. That is shown in the maintenance of the windows shutters which can significantly improve the performance of reducing the heat and provide natural ventilation. The maintenance of the old wooden wall cladding and using the same wooden doors and windows shows a perfect material conservation. They also fix the damages that happened to the external iron site gates & the internal stairs handrail. *(Figure 14. Below shows the interior & exterior maintenance for different materials)*

### **3.2.5 Indoor environmental quality:**

Villa Zogheb is using the natural ventilation procedure to contribute the comfort and well-being of building occupants by establishing minimum standards for indoor air quality. The environmental tobacco smoke control can be achieved by prohibits smoking in the building. By prohibit, smoking outside the building except in designated smoking areas located at least 25 feet (7.5 meters) from all entries, outdoor air intakes, and operable windows. Green cleaning policy can be achieved by having in place a green cleaning policy for the building and site. At a minimum, the policy must cover green cleaning procedures, materials, and services that are

within the building and site management's control, and include the building responsible for cleaning the building and building site.



Figure 14. Interior & Exterior maintenance for the original materials (by author)

### Conclusion:

The past three examples have used different practices of sustainable preservation. It is obvious that the main purpose of applying these practices on heritage buildings is to keep them alive and in use. The examples used the sustainable preservation methods with a respect of their original materials, a replacement of the missing or decayed parts and refinement the building. This paper has reviewed a broad understanding of what is meant by sustainable preservation of heritage buildings:

- The preservation of heritage buildings is considered urgent for the economic reality especially in developing countries.
- Preservation is not only a conservation process but is also a kind of creating a new image accentuating the cultural and historical identity in the country.
- The policy of preservation contains several studies: First evaluating the buildings which should be preserved and classifying it according to its importance. Second, identifying the system of treatment of the building with value according to its condition and the urban point of view of the decision maker. Third, analysing the visual image of the building and the surrounding area. Forth, surveying and achitectural registration of the building and its constructional condition. Finally, visualizing different options for a new function to the building and choosing the best.
- Projects like these demonstrate sustainable preservation as an economic and community revitalization tool, and act as a catalyst for change in the most needed areas of urban centres.

### General Recommendations:

Recommendations for the sustainable preservation process of heritage buildings:

- Ensure understanding the significance of a building and its historic features, architecture and contribution to the locality, including the context and setting.
- Ensure having enough information to properly understand the likely impact of your intervention; obtain or undertake professional survey inclusive of archaeological

records; minimise the physical and visual impact of any work or new equipment, including any matching, blending or complementing any new work or reinstatements.

- Avoid damage to significant historic fabric by intervening as little as possible.
- Ensure that there is no unnecessary loss of significant features of special interest.
- Avoid removing fixtures, fittings or features of historic interest, but if unavoidable make a record. Look at all the options for improving performance and environmental sustainability and look for precedents elsewhere.
- Use traditional building techniques and those proven to work on the building previously.
- Test any new materials and systems and research accordingly.
- Consider the supplementing of traditional building techniques with caution.
- Use new equipment such as solar panels and wind turbines sensitively and ideally off the building concerned.

At the end it is vital to understand that heritage buildings are a finite resource and that in their existence there is not only embodied energy and carbon but the spirit and identity of the country. Likewise in the drive towards sustainable design we should ensure that local distinctiveness and character is retained.

### **References: Articles, Literature & Electronic References**

- Barbara Campagna, (2008), "How changes to LEED will Benefit Existing and Historic Buildings." Forum News: National Trust for Historic Preservation vol. XV, no. 2 .
- Bethany N. Johnson (2009) , "Respect and reuse: sustainable preservation in portland, oregon" .
- Brundtland, Gro Harlem, (2010) (World Commission on Environment and Development, Report of the World Commission on Environment and Development: "Our Common Future." [1987]) (United Nations General Assembly(U.N.G.A))
- Bullen, P.A. and Love, P.E.D., (2010), "The rhetoric of adaptive reuse or reality of demolition: views from the field", Cities, Vol. 27 No. 4, pp. 215-24.
- Burra Charter, (2010), the Australia ICOMOS CHARTER for places of cultural, significance, with associated guidelines and code on the ethics of coexistence. Articles, Explanatory Notes and the flow chart, 2010)
- Kathryn Rogers Merlino (2011). Report on Historic Preservation and Sustainability, prepared for Washington State Department of Archeology and Historic Preservation, Department of Architecture University of Washington.
- M.Richard ,(2013) "Sustainability Report 2013 – Ca' Foscari University of Venice ".
- Richard Moe, (2007), president National Trust for Historic Preservation "Sustainable Preservation: Historic Preservation's Essential Role in Fighting Climate Change," presentation notes, Washington, DC, December 2007,
- Michael Redclift and Ted Benton, (1994) "Social Theory and the Global Environment. Michael Redclift and Ted Benton, editors"
- Nancy B. Solomon.,(2003) : "Tapping the Synergies of Green Building and Historic Preservation." Architectural Record vol. 191, no. 7 (156)
- (Rick Fedrizzi , President, (2013), CEO & Founding Chairman , U.S. Green Building Council). <http://www.preservationnation.org/issues/sustainability/sustainability-preservationl.html>
- Routledge, 2004 , Giving Preservation a History, Histories of Historic Preservation in the United States
- Journal of Dairy Science Vol. 96 No. 9, 2013 Invited review: Sustainability of the US dairy industry Article in Journal of Dairy Science-
- The WBDG Historic Preservation Subcommittee,2017 - SUSTAINABLE HISTORIC PRESERVATION –
- <https://www.wbdg.org/design-objectives/historic-preservation/sustainable-historic-preservation>.
- [https://en.wikipedia.org/wiki/Ca%27\\_Foscari](https://en.wikipedia.org/wiki/Ca%27_Foscari)

# The Thermal Behaviour and Embodied Energy of Hemplime Construction

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**Abstract:** The transient energy ratio (TER) is a recent metric which measures the divergence between steady-state analysis and transient analysis in terms of heat transfer. This divergence is caused by the thermal mass of a building; in most buildings, it is the walls that contribute most to the overall thermal mass. The thermal mass of a building's walls can cause either an increase or decrease in heating/cooling energy use (as compared to a static analysis), depending on a range of variables including heating strategy and weather/climate parameters. Hemplime concrete is a material which has the potential to offer improvements over traditional construction types thanks to its thermal properties, hygroscopic nature, and low-environmental-impact production methods. As with any material, thicker walls with lower thermal transmittance can reduce the energy required to heat or cool the interior space, but this benefit ought to be balanced with the embodied energy in the thicker walls. This work draws on recent developments in the use of the TER technique and life cycle analyses (LCA) of the embodied energy and carbon in hemplime concrete to estimate the total lifetime energy use for hemp walls in typical Cfb Köppen climate zones.

**Keywords:** Embodied energy, Hemplime concrete, Hemp concrete, Thermal properties, Thermal mass

## Introduction

Bio-based materials, such as hemp-lime, offer a sustainable alternative to contemporary building products. Typical wall infill materials such as synthetic insulation products and dry-wall, for example, exhibit high embodied energy due to the intensive processes of manufacture. As such it is widely accepted that bio-based materials can help foster a more sustainable future for the built environment, however as yet there is a paucity of extensive knowledge of their effect on building energy both in operation and in construction.

Characterisation of the embodied energy, and embodied carbon, allows for an understanding of the materials of construction beyond their finished state, to include the geographies and processes of their extraction, production, transport and assembly (Andraos, 2016). During each of these stages of the material's life cycle, energy is consumed. No definitive life-cycle analysis of hemp has been published even though authors have consistently referred to hemp as a carbon negative material, citing other works that have claimed similar. Certainty when mixed with lime to form hemp-lime the associated embodied energy increases due to the reported high embodied energy of lime (Jones and Hammond, 2008).

When in situ, and enveloping a conditioned space, a wall-material's unique physical characteristics affect the thermal environment and the associated energy consumption. Typically wall constructions are characterised by their thermal resistance or, more commonly their thermal transmittance (or U-value). Studies have most commonly reported values in the range of  $0.12 \text{ Wm}^{-1}\text{K}^{-1}$  for 300mm walls (Walker and Pavía, 2014) – a common thickness of hemp-lime construction. However, it is widely acknowledged that the U-value alone does not capture the complete thermal performance of hemp-lime: although a relatively lightweight composite material ( $\rho=330\text{--}550 \text{ kg/m}^3$ ), hemp-lime has a high specific heat capacity and exhibits hygroscopic behaviour.

The behaviour of hemp-lime in the corresponding transient heat up and cool down phases is not particularly well documented. Some recent studies of whole hemp buildings have presented insightful results of the dynamic performance of hemp based walls (Shea et al, 2012), but the real effect of thermal mass remains non-quantified. With the aim of quantifying the impact of high thermal mass, heavy walls on building energy consumption, Reilly and Kinnane (2017a) recently published the Transient Energy Ratio (TER) method. This method goes beyond a standard steady-state characterisation of walls to also capture the performance of the wall during the transient phases.

This paper aims to add to the understanding of hemp-lime construction by advancing the knowledge of the energy impact of hemp-lime construction in operation and construction. The embodied energy and the operational energy, combined, form the total energy requirement of a building, and only by considering these together can an accurate picture of the total impacts emerge; optimisation of one aspect alone cannot describe the full situation. This paper calculates the embodied energy of a cement-free hemp-lime composite that has been cast, and evaluates the thermal performance using the TER. By doing so it estimates the total lifetime energy use of hemp-lime walls.

## **Methodology**

### ***Intermittent Heating and the Transient Energy Ratio***

High thermal mass building elements can provide a thermal store, or buffer, during periods of outdoor temperature fluctuations. By doing so, they can reduce the need for active heating or cooling, and potentially reduce overall energy use. However, by decreasing the response rate of a building's structure to temperature changes, thermal mass can also contribute to greater energy use. This is most likely to occur when buildings are occupied only intermittently – as many buildings are.

The transient energy ratio is a parameter that quantifies the departure from steady-state thermal conditions during building heating and cooling. It incorporates the detail of the construction, dynamic material properties, and building occupancy schedule, but in such a way as knowledge of the building geometry is not needed. In this way, it can be used for more general studies than (for example) detailed modelling of particular buildings. The method is described in summary below (from Reilly and Kinnane, 2017b):

- Calculate the U-value for the wall section in question (termed U)
- Simulate the thermal behaviour of the wall, using boundary conditions representative of the climate and indoor occupancy pattern of interest
- Use the actual energy flow through the wall in the dynamic simulation to calculate an effective U-value (termed  $U_e$ )
- Divide  $U_e$  by U to find the transient energy ratio (TER)

The dynamic simulation is necessary to capture the true behaviour of the walls. In conditions of changing surface temperatures, heat may be stored and returned to the indoor and outdoor environment: this is the basis of thermal mass. A dynamic simulation attempts to capture these effects by modelling the response of a wall to varying temperatures. The effective U-value is the quantity which, when used with the mean temperatures, gives the actual energy flow through the wall.

This actual energy flow may be greater or less than that predicted based on the static U-value, and this ratio is termed the TER. If the TER is less than one, the thermal mass of the wall offers energy savings, over and above any savings purely due to a low conductivity. On



the other hand, if the TER is greater than one, the wall is leading to greater energy use than predicted by a static analysis.

### *Static Analysis*

The static analysis was simply an evaluation of each wall's U value, calculated in the standard manner as in Equation 1 below (where L is the thickness of each material, k is the conductivity, and the subscript indicates the material).

$$\frac{1}{U} = \frac{L_1}{k_1} + \frac{L_2}{k_2} + \dots + \frac{L_n}{k_n} \quad (\text{Equation 1})$$

### *Dynamic Analysis*

The principle of the TER method is to use a dynamic simulation of a wall section. To comply with the method, any simulation method that accurately predicts internal wall temperatures may be used. For this work, a finite element (FE) model was created using commercial FE software (Abaqus 6.12). The walls were modelled using heat transfer elements with a typical mesh dimension of around 1 mm, and the increment time in the model was set such that in no step did the temperature change exceed 0.1 K. Heat transfer at the wall surfaces was modelled according to ISO 6946, as in Eqn. 2 below. (Where  $\bar{v}$  is the mean wind speed,  $\epsilon$  the emissivity,  $\sigma_0$  the Stefan-Boltzman constant and  $T_0$  the relevant environmental temperature.)

$$h = 4 + 4\bar{v} + 4\epsilon\sigma_0 T_0^3 \quad (\text{Equation 2})$$

Solar flux was applied to the outside face as a power input per unit area. The output from the model, is a heat flux on the interior surface of the wall ( $\text{W/m}^2$ ). This average heat flux per unit area was divided by the mean temperature difference to give the effective U-value. In this way, the effective U-value accurately reflects the heat loss/gain through the wall, but has units of  $\text{W/m}^2/\text{K}$ , making it directly comparable with the standard U-value calculated through a static analysis.

Hemplime concrete is the subject of study for this paper; results for this are compared with an equivalent analysis for a typical brick and blockwork cavity wall.

### ***Embodied Energy***

The concept of embodied energy dates back to at least 1984, and the concept of whole lifecycle energy analysis has become widely understood. In essence, the embodied energy in a product is the total energy required to produce said product; however, there are very many possible ways to quantify this total. Many groups have produced different, sometimes conflicting, definitions and methods. Probably the most widely agreed-upon definition now is that proposed by Cleveland and Morris: "[Embodied energy is] the sum of the energy requirements associated, directly or indirectly, with the delivery of a good or service" (Cleveland and Morris 2009, McAllinden 2015); and in the context of the construction and building sectors the terms cradle-to-gate, cradle-to-site, cradle-to-grave and cradle-to-cradle have gained acceptance and understanding. The most widespread approach is probably that outlined by ISO (ISO standards 14040/44); however, there remain numerous flaws with this methodology, and different assessments of the same product – for nominally the same conditions – can produce very different results (Reap et al 2008, Curran 2015). Despite these shortcomings, several databases exist containing lifecycle assessments of products, goods and materials suitable for different purposes, of which some of the most cited are those produced by the University of Bath (the ICE database), Ecoinvent and the European Commission's Platform on Lifecycle Assessment. The ICE database has not been updated since

2011 and further material data is regularly called for to optimise and verify material life cycle inventories and Environmental Product Declarations (Moncaster and Symons, 2013).

Embodied carbon is a concept that is closely related to embodied energy; as generally defined, it is the total emissions of greenhouse gasses associated with a product, measured in kg carbon dioxide equivalent (as in, with equivalent global warming potential over a 100 year timeframe). Many similar considerations apply to embodied carbon as to embodied energy; and two of the more controversial aspects with both are the issues of ecological versus manmade energy contributions, and carbon sequestration. In the context of hemplime concrete, these are both of crucial importance, as outlined in the section below.

## **The Embodied Energy of Hemplime**

### *Photosynthesis and Carbon Sequestration*

Hemp derives the energy it needs to grow from sunlight via the C3 photosynthesis pathway, which is around 3% “efficient” when measured in terms of the proportion of sunlight converted to stored chemical energy. Most of the energy used in subsequent processing of hemp is from an electrical source and the emissions are dependent on the local energy mix in the supply. In qualitative terms, there is a clear difference between an energy input where the source is photosynthesis from sunlight, and manmade power generated from (for example) fossil fuels. However, in quantitative terms, the difference is not so obvious, and unfortunately many sources choose figures that show their preferred product in the best light. This is not to imply deliberate attempts to mislead on the part of any authors: unintentional bias is all too easy when the subject matter is complex. Those wishing to maximise the advantages of hemp will ignore the energy contribution made by photosynthesis (with reasonable justification that such energy inputs are irrelevant in terms of global warming), whereas those wishing to maximise the disadvantages will lump all energy inputs together.

A similar but more complicated situation arises with consideration of carbon sequestration. Hemp that is used for buildings does, in a sense, ‘lock away’ the carbon dioxide that was converted to biomass. The most influential recent analysis of the embodied energy of hemp (Boutin et al, 2005 and 2013) subtracts this carbon from the carbon emitted during construction, to claim that hemplime concrete is a “carbon-negative” construction material. By this, it is meant that the construction of a building made from hemplime concrete will actually result in a lower concentration of CO<sub>2</sub> in the atmosphere than if the building had not been built, and there are many claims to this end (see for example, Renger et al, 2015). However, in order to produce this result, it is necessary to assume (a) that all the CO<sub>2</sub> absorbed during growth and recarbonation of the building remains permanently locked away, and (b) to ignore any other alternative use of the land: leaving the land fallow may result in greater plant growth, and possibly greater carbon storage than is possible in hemp. Which process is dominant, has yet to be firmly established.

Gorte (2007) analysed the process of carbon sequestration in wood products more generally, and produced a good summary. Although a decade old, there is still no solid answer, and his summary is still valid:

In this context, timber harvesting is an especially controversial forestry practice. Some argue that the carbon released by cutting exceeds the carbon stored in wood products and in tree growth by new forests. Others counter that old-growth forests store little or no additional carbon, and that new forest growth

and efficient wood use can increase net carbon storage. The impacts probably vary widely, and depend on many factors, including soil impacts, treatment of residual forest biomass, proportion of carbon removed from the site, and duration and disposal of the products. To date, the quantitative relationships between these factors and net carbon storage have not been established.

This paper aims for a reliable estimate of the embodied energy in hemplime concrete. Most authors working in the field would intuitively posit that hemplime has a much lower embodied energy than that of concrete, but such intuitions should be backed up by reliable data.

### ***Hemplime Used in this Study***

A range of hemp based concretes have been developed during the course of a long running research project initiated by Walker and Pavía who assessed their mechanical (Walker, Pavía and Mitchel, 2014) and hygrothermal (Walker and Pavía, 2014) properties. Subsequently acoustic characterisation (Kinnane et al, 2016) and further thermal investigation (Kinnane et al 2015, Reilly and Kinnane 2017) has been undertaken by these authors.

The specific concrete used in this study is a composite of hemp shiv and lime dominant binder, with additional Ground Granulated Blast Slag (GGBS). The shiv is the chopped fragments of the woody core of the hemp plant. It ranges in size from approximately 4 mm up to 10 mm (Kinnane et al, 2016- see Figure 1). A hydrated lime (CL90) is mixed with GGBS in a 70:30 ratio. In its hydrated state the lime exists as calcium hydroxide (Figure 2). The GGBS also contains a high calcium content but also silicates and aluminates that react with the addition of water. The shiv is the aggregate of the concrete and this is first mixed with the binder. This dry pre-mixing of the hemp with the binder, and the subsequent staggered addition of water to create a slurry is described in more detail in Walker and Pavía (2014). The final hemp-lime concrete has a ratio of constituents of 2:1:3.1 by weight of binder:hemp:water.

To develop walls of approximately 1 m<sup>2</sup> surface area for analysis the hemp-lime concrete is cast in shuttering with a void width of 300 mm. The material is poured and tamped into the shuttering resulting in hemp-lime walls with a measured density of approximately 565 kg/m<sup>3</sup>.

Table 1 below lists the indicative CO<sub>2</sub>e for the main constituents of the hemp-lime test under consideration. Values for cement are included for comparison.

Table 1. Embodied energy and carbon of constituent materials.  
Sources: (1) Jones and Hammond 2008, (2) Clear et al 2009, (3) Higgins 2007

<b>Constituent</b>	<b>MJ/kg</b>	<b>CO<sub>2</sub>e (kg CO<sub>2</sub>e/kg)</b>	<b>Source</b>
Cement (avg CEM I)	5.5	0.913 – 0.95	1, 2
Cement with 21-35% GGBS (CEM II/B-S)	4.77 – 4.21	0.77 – 0.65	1
Lime	5.3	0.78	1
GGBS	1.3	0.067 – 0.07	2, 3
Hemp	10		Present work



Figure 1: Samples of the hemp particles used in this study (previously published in Kinnane et al, 2016)

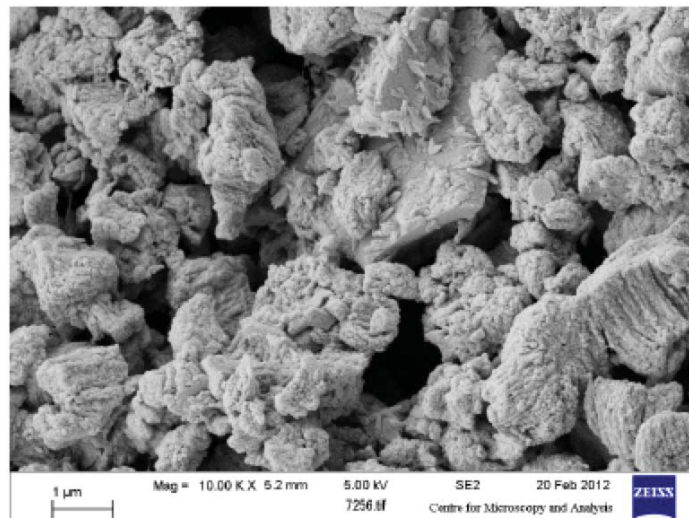


Figure 2: Scanning electron microscope image of the hemplime used in this study (previously published in Kinnane et al, 2016)

The embodied energy effect of using GGBS is most commonly presented when it is included in a concrete mixture. Kelly et al (2010) allocate no embodied energy to GGBS when it is added as a 50% cement replacement to concrete. Hence, this reduces the embodied energy of the concrete by half. In the context of this review no experimental study was found that actually specifies an embodied energy value for GGBS, likely due to the difficulty in specifying a definite value for a co- or by-product, as it is. In a briefing document Higgins (2007) wrote that the energy usage of 1 tonne of GGBS is 1300 MJ, with a corresponding CO<sub>2</sub> emission of just 0.07 tonne.

One of the unexpected outcomes of the investigation is the fact that lime is listed with a similar, and following the addition of GGBS, a higher embodied energy to cement (Table 1). Lime is commonly assumed as a more environmentally friendly alternative to cement. The authors of the ICE database note that because lime is fired at a lower temperature does not necessarily imply a lower embodied energy; instead yield, density and time in the kiln are all

essential parameters. Lime does have a lower embodied carbon due to a more favourable fuel mix and lower process related carbon dioxide emissions (Jones and Hammond, 2008). An additional benefit of using a lime-based mortar is that it allows for deconstruction at end of life, in contrast to (necessary) demolition when using cement; and the carbon sequestration potential of lime is generally higher than that of cement, depending on the exact composition of each. Certainly a full life cycle assessment of lime, and the many varieties of lime, is called for. The ICE database only gives a value for 'general lime' although hydrated lime and natural hydraulic limes undergo quite different processes.

#### *The Embodied Energy of Hemp*

Hemp is commonly referred to as a material with a negative embodied energy as it consumes CO<sub>2</sub> during its growing life. However, some energy is required both to harvest the plants and process the shiv. The ICE database documents an average value of 9.43 MJ/kg for timber, and a value of 7.11 MJ/kg for general timber. Studies that have evaluated an embodied energy for hemp document similar values, ranging from 6.8 (Shen and Patel, 2008) to 13.2 (Gonzalez-Garcia et al, 2010) MJ/kg, once sequestration is ignored. Hemp is less dense than most timber, which tends to increase the energy required per unit mass for transport and processing; but less drying is required for hemp, which is the dominant energy contribution to the overall embodied energy of timber (and a significant difference is observed between the values for air-dried and kiln-dried timber). Despite recent research, the authors do not consider that there is enough reliable evidence to state with any confidence whether secondary effects such as carbon sequestration are positive or negative. Hence, for the purpose of this study a mid-range and approximate value of 10 MJ/kg is assumed. Table 2 gives secondary factors that could affect the overall carbon balance, but that are at present unquantified.

Table 2. Potential global warming effects of hemp growth unaccounted for in this study, listed in decreasing order of certainty.

<b>Global cooling effect</b>	<b>Global warming effect</b>
Carbon sequestration in hemp	Carbon release from decomposing hemp at eventual demolition
Enhanced carbon capture from fast-growing hemp	Reduced carbon capture compared to forestry
Increased albedo (compared to bare earth)	Reduced albedo (compared to transpired cloud formation over old growth forests)

#### *Comparison with a Cavity Wall*

Taking the values listed in Table 1 for the embodied energy of the constituent materials, and the water:hemp:binder ratio for the hemplime concrete used in this work, allows a calculation of the overall embodied energy. This gives a value of 3.0 MJ/kg, which is in line with the older estimate of Boutin et al (2005) for hemplime of 3.2 MJ/kg.

In order to convert the material properties to usable values for a wall, it is necessary to define a functional unit: in this case, a wall of 1 m<sup>2</sup> is used. The wall construction details for both the hemplime wall and a typical cavity wall are given in Table 3 along with the thermal properties of the materials.



Table 3. Wall construction types. The properties of hemplime are taken from Walker and Pavia (2014), other thermal properties are based on a review work by Clarke (1990).

Wall type	Material	Thickness (mm)	Conductivity ( $\text{W m}^{-1} \text{K}^{-1}$ )	Diffusivity ( $\text{mm}^2/\text{s}$ )
Cavity wall	Plaster	12.5	0.52	1.71
	Insulation	40	0.055	1.74
	Blockwork	100	0.44	0.451
	Cavity insulation	150	0.047	0.582
	Brick	102	0.721	0.472
Hemp-lime	Plaster	12.5	0.52	1.71
	Hemp-lime concrete	450	0.12	0.5
	Lime render	40	0.7	0.52

Taking into account the thicknesses and densities of each material layer, gives the overall embodied energies for each wall as 393 MJ/m<sup>2</sup> for the hemplime wall, and 2270 MJ/m<sup>2</sup> for the masonry cavity wall. Despite the much greater mass of the masonry, this is not the largest contribution to the embodied energy: the largest contribution, by far, comes from the synthetic insulation (in this example, polystyrene insulation was assumed). However, even given the uncertainties in the values – which are large, substantial, and in need of quantification – it seems that hemplime concrete has a significantly lower embodied energy than masonry and synthetic insulation combinations.

### Thermal Performance

In order to assess the thermal performance of these walls, the TER method was used as described in the Methodology section. This allows a genuine assessment of the impact of these two wall types on the operational energy use, in such a manner that extraneous effects (e.g. glazing area, ventilation, etc) are ignored in a way that is not possible with conventional building simulation. The two walls were put through a simulated year to generate the TER values, as described in detail in Reilly and Kinnane (2017a). (The thickness of the hemplime wall was increased in the modelling study compared to the cast wall to match static U-values between the cavity and hemplime walls.)

The location modelled was Belfast, Northern Ireland; the operational energy must be adjusted for other locations to take account of the difference in degree-days of heating, but importantly, the TER value remains essentially invariant within a climate zone, so this analysis is relevant to any region with a temperate maritime climate.

Figure 3 shows the importance of a dynamic simulation: this figure shows the temperatures on the indoor and outdoor wall surfaces when the two walls are subject to morning and evening heating, such as is typical for domestic use during weekdays. The indoor surface temperature takes some time to rise to the air temperature at the start of the heating period, and the whole wall remains several K above the outside temperature for hours afterwards. A calculation of the operational energy use assuming steady-state conditions would not capture these effects.

The overall effect of the thermal mass of the walls is to increase the overall energy use: the energy use is more than double that predicted by a static analysis. Table 4 gives the TER, U-values, and effective U-values for the two walls. If two walls have different transient energy

ratios, this indicates that their dynamic thermal response is different, independently of any difference in thermal resistance. For example, a straw bale wall and a solid earth wall with different thicknesses but the same overall thermal resistance would have different TERs, as they behave differently under dynamic conditions. In this case, despite the differences in wall construction detail and thermal properties, the two walls behave in a very similar way, even during changes in temperature. The indoor surface of the hemp wall remains approximately 1 K above the indoor surface of the cavity wall during cooling; however, this small difference does not have a substantial effect on the total operational energy used by the two walls.

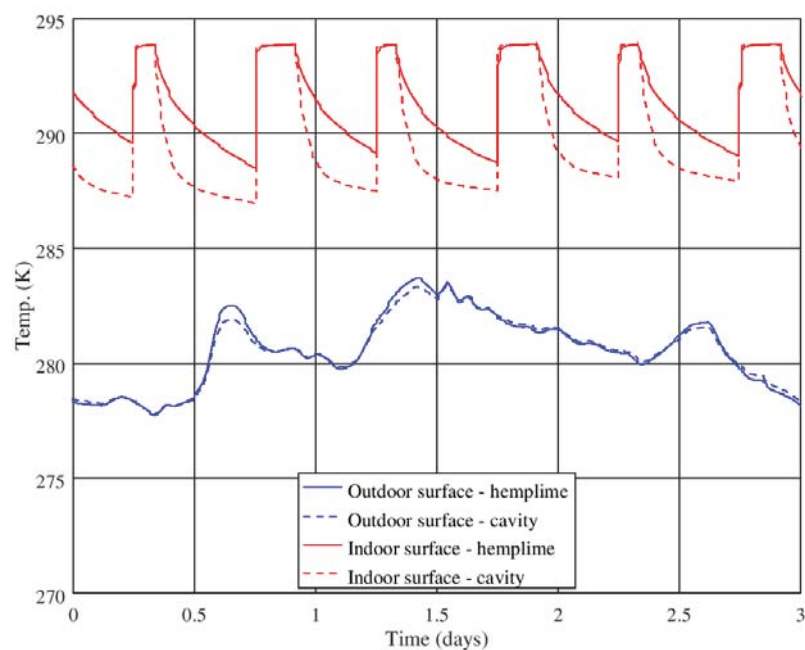


Figure 3: Wall surface temperatures for a three-day period.

Table 4. Wall thermal response.

Wall	$U$ $W/m^2/K$	TER	$U_e$ $W/m^2/K$
Hemplime	0.26	2.59	0.68
Cavity	0.23	2.57	0.6

## Discussion

The total energy use for a building is made up of two components: the embodied energy, and the operational energy. For oceanic, temperate climates, where large amounts of energy are often used to modify the indoor environment, increasing the insulation level or thickness of a wall reduces the operational energy use, but increases the embodied energy. Figure 4 shows the embodied energy as a proportion of total energy for these two walls. With the cavity wall, even after 100 years, the embodied energy still represents around  $\frac{1}{3}$  of the total energy input. For the hemplime wall, this proportion falls to less than 10% at 65 years.

From the perspective of environmental damage, hemplime walls do indeed appear to be significantly less harmful than conventional cavity walls. However, this is not due to their thermal properties as is often claimed, as the thermal performance is very similar. The dynamic behaviour – which is a consequence of the thermal mass – is almost identical, in this study, to the behaviour of a masonry cavity wall. The benefit of the hemplime wall arises because of the lower energy associated with its production; in particular, it avoids the use of synthetic polymer based insulating products, which have very high embodied energies.

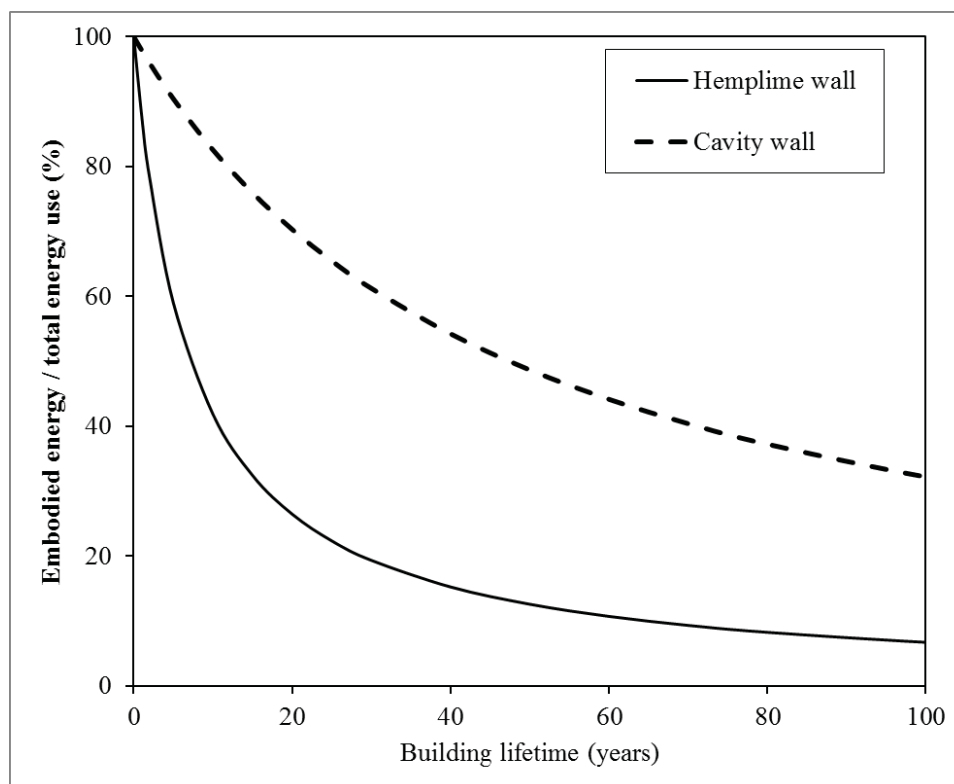


Figure 4: Embodied energy as a proportion of total energy use.

## Conclusions

These two walls appear very different: the hemplime wall is monolithic, whereas the cavity wall has multiple layers performing different functions, with very different mechanical and thermal properties. Despite this, the overall thermal performance of the two walls is very similar. Many claims are made in the literature for the superior performance of hemplime walls due to their thermal mass, but this analysis shows this not to be the case: the dynamic performance of the hemplime wall is very similar to the dynamic performance of the cavity wall. Of course, additional insulation could be added to improve either wall's performance; the thicknesses and levels of insulation used here are typical of contemporary construction.

Since the two walls perform very similarly in operation, any difference between them over the whole operational life is likely due to the difference in embodied energy, and in this regard, the hemplime wall appears to be a clear winner. There are of course many uncertainties in both these analyses, and any design decisions would be much better advised to use specific data rather than the necessarily broad assumptions made in this paper; but it does seem as though hemplime is likely to be the more environmentally sound choice overall. The analysis presented here has attempted to be as neutral as possible; owing to the balance of factors in Table 2, it is likely that the estimate of the embodied energy of the hemplime wall is a slight overestimate, although this does need to be verified.

The field would benefit from a full study of the embodied energy and carbon associated with lime. At present, only very general values are available, even though there are wide variations in processing methods; consequently, there is large uncertainty associated with the use of general embodied energy values for lime, and more specific results would be of benefit. However, it is unlikely that this would change the general trend of the results, as – as shown in Figure 4 – the embodied energy of hemplime walls makes only comparatively small contributions to the overall energy use in most cases.

## References

- Andraos A. (2016) What Does Climate Change (For Architecture)? [Online] The Avery Review [cited 2017 Sep 23] Available from: <http://averyreview.com/issues/16/what-does-climate-change>
- Boutin, M.-P., Flamin, C., Quinton, S., & Gosse, G. (2005). Analyse du cycle de vie de: mur en béton de chanvre banché sur ossature en bois, INRA, Lille, France
- Boutin, M.-P. and Flamin, C. (2013) Examination of the Environmental Characteristics of a Banked Hempcrete Wall on a Wooden Skeleton, by Lifecycle Analysis: Feedback on the LCA Experiment from 2005, in Bio-aggregate-based Building Materials (eds S. Amziane, L. Arnaud), John Wiley & Sons, Hoboken, USA
- Clarke, J.A.; Yaneske, P.P. & Pinney, A.A. (1990) The Harmonisation of Thermal Properties of Building Materials. Technical Report, Building Research Establishment, Watford, UK
- Clear C, Higgins D, Sear L. (2009) Embodied CO<sub>2</sub> of UK cement, additions and cementitious material, fact sheet 18 (P1). British Cement Association (BCA)
- Cleveland, C.J. & Morris, C.G. (eds.) (2009). Dictionary of Energy: Expanded Edition Expanded. Elsevier, Amsterdam, Netherlands
- Curran M.A. (2015) Life Cycle Assessment: a review of the methodology and its application to sustainability, *Current Opinion in Chemical Engineering*, 2(3):273-277
- Densley Tingley, D. & Davison, B. (2011). Design for deconstruction and material reuse. *Proceedings of the ICE - Energy*, 164, 195-204
- González-García S, Hospido A, Feijoo G, Moreira MT. Life cycle assessment of raw materials for non-wood pulp mills: hemp and flax. *Resour Conserv Recycl*. 2010;54(11):923–30.
- Gorte R.W. (2007), Carbon Sequestration in Forests, Congressional Research Service Report RL31432, Washington D.C., USA
- Higgins D. (2007) Briefing: GGBS and sustainability. *Proc. Inst. Civ. Eng. – Constr. Mater*. 160(3):99–101.

- ISO 14040:2006: Environmental management -- Life cycle assessment -- Principles and framework, International Organization for Standardization, Geneva, Switzerland
- ISO 14044:2006: Environmental management -- Life cycle assessment -- Requirements and guidelines, International Organization for Standardization, Geneva, Switzerland
- Jones C, Hammond G. (2008) Embodied energy and carbon in construction materials. *Proc Ice - Energy*. 161:87–98.
- Kelly A, Goggins J, Keane T. (2010) The assessment of embodied energy in typical reinforced concrete building structures in Ireland. [online, cited 2017 Sep 28]; Available from <https://aran.library.nuigalway.ie/handle/10379/3826>
- Kinnane O, Mcgranaghan G, Walker R, Pavia S, Byrne G. (2015) Experimental investigation of thermal inertia properties in hemp-lime concrete walls. In *Advanced Building Skins*, Bern, Switzerland, Sept. 2015
- Kinnane O, Reilly A, Grimes J, Pavia S, Walker R. (2016) Acoustic absorption of hemp-lime construction. *Constr Build Mater*. 122(Supplement C):674–82.
- McAllinden (2015) Embodied Energy and Carbon Briefing Sheet, Institute of Civil Engineers, London, UK
- Moncaster AM, Symons KE. (2013) A method and tool for ‘cradle to grave’ embodied carbon and energy impacts of UK buildings in compliance with the new TC350 standards. *Energy Build*. 66(Supplement C):514–23.
- Reap J, Roman F, Duncan S, Bras B (2008) A survey of unresolved problems in life cycle assessment. *Int. J. Life Cycle Assess*. [2 part article] Part 1: goal & scope and inventory analysis 13(4); Part 2: impact assessment and interpretation 13(374)
- Reilly A, Kinnane O. (2017a) The impact of thermal mass on building energy consumption. *Appl. Energy*. 198:108–21.
- Reilly A, Kinnane O. (2017b) An assessment of the thermal storage capacity of hemp-lime using the Transient Performance Ratio method. In *ICBBM*, Clermont, France, July 2017
- Renger B.C., Birkeland J.L. & Midmore D.J., Net-positive building carbon sequestration (2015), *Building Research & Information*, Volume 43, 2015 - Issue 1 (early online version available 2014)
- Shea A, Lawrence M, Walker P. (2012) Hygrothermal performance of an experimental hemp–lime building. *Constr. Build Mater*. 36:270–275.
- Shen L, Patel MK. (2008) Life Cycle Assessment of Polysaccharide Materials: A Review. *J Polym. Environ*. 16(2):154–67.
- Walker R, Pavia S. (2014) Moisture transfer and thermal properties of hemp–lime concretes. *Constr. Build Mater*. 64(Supplement C):270–6.
- Walker R, Pavia S, Mitchell R. (2014) Mechanical properties and durability of hemp-lime concretes. *Constr. Build Mater*. 61(Supplement C):340–8.



# Second International Conference for Sustainable Design of the Built Environment: Research in Practice - SDBE 2018

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